PULPWOODS

of the

UNITED STATES AND CANADA

VOLUME I — CONIFERS

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THIRD EDITION

Appleton, Wisconsin

The Institute of Paper Chemistry

1980

INTRODUCTION

A large number of tree species are pulped in the United States and Canada. Much information is available on certain of these species but, unfortunately, such data are scattered in a wide variety of publications. This book brings together this scattered information from silvics to pulping properties.

Several sections have been enlarged in this new edition, and information has been added on bark, including structure, physical properties, and chemical composition. As in the previous edition, the range of a species is shown on a map. Information on four exotic species that are planted in the United States has also been added; these are *Pinus sylvestris* (Scotch pine), *Picea abies* (Norway spruce), *Larix decidua* (European larch) and *Larix leptolepis* (Japanese larch).

The author and revisers acknowledge with thanks the assistance received from members of the Institute of Paper Chemistry staff in assembling the data. Special thanks go to Dean W. Einspahr, John D. Litvay, Thomas J. McDonough and the Editorial, Photography and Duplicating staff.

Five summary tables are located at the back of the book. These are Table I – Tracheid Dimensions and Decay Resistance, Table II – Wood and Bark Specific Gravity, Table III – Calorific Value of Wood and Bark, Table IV – Chemical Composition of Wood, and Table V – Chemical Composition of Bark.

EXPLANATION OF TERMS

Units of Measurement

Both English and metric units are given wherever possible.

Tree Name

The common name, scientific name and synonyms were largely taken from the USDA, Forest Service Agriculture Handbook no. 519, 1978 (Little, E.L., Jr. Important Forest Trees of the United States).

Range

The general area in which the species is indigenous is shown on a map when feasible. Altitudinal range is also given if limiting and available, as well as the acreage covered. It must be remembered that certain localities within the range may not contain the tree because of environmental conditions, natural enemies, or removal by man.

Dimensions

Average dimensions of mature trees are given.

Pathology

Major disease and insect enemies of each species are briefly mentioned. Much of this information concerns the trees and far less of it, the logs. Unfortunately, there is no direct relationship between the pathological resistance of a growing tree and the durability of the wood cut from it. Certain types of diseases do not interfere with the use of wood for chemical pulping; others cause so much decay that the tree is useless.

Gross Features of the Wood

The general characteristics and properties of the typical wood from the merchantable part of the tree are given. When the planes of section are described, x signifies cross, r signifies radial, and t signifies tangential.

Microscopic Structure of Wood and Bark

The minute anatomy of wood and bark is described with dimensions and characteristics normally present. Weight factor and fiber coarseness data have been added where possible. Photomicrographs illustrating wood and bark structure at higher magnifications are scattered throughout the report. Additional information on the bark of 42 species may be obtained from The Institute of Paper Chemistry, including test results of simulated hammermilling, bark toughness and strength, and wood/bark adhesion. This work was done under the Institute's Project 3212, "Bark and Wood Properties of Pulpwood Species as Related to Separation and Segregation of Chip/Bark Mixtures."

Physical Properties of Wood

Several common values do not have to be determined by stress. Specific gravity is based on the oven-dry weight and the volume of the material when it was in a green, air-dry, or oven-dry condition. The density is given in pounds per cubic foot for various conditions of moisture and also as pounds of dry wood substance per cubic foot volume when green. Much information has also been added on specific gravity variation within the tree and changes in specific gravity due to fertilization, geographic location, etc.

The moisture content is the average for green wood. It is the custom in wood industries to relate the loss in moisture from the original to the oven-dry condition to the weight of the oven-dry piece, whereas in the pulp and paper industry moisture is expressed as a percentage of the original weight as it is with chemicals. Both values are given as well as relative sapwood and heartwood moisture content where available.

Most woods have their cell walls saturated and the cell cavities free from water (fiber saturation point) at a moisture content of 25 to 30% (based on the oven-dry weight). When the moisture content decreases below the fiber saturation point, shrinkage takes place. The shrinkage values for volume, radial direction and tangential direction are figured on the loss in size to the oven-dry condition based on the dimension when green; the shrinkage to the air-dry condition will be less.

Physical Properties of Bark

Information on the specific gravity and moisture content of bark has been added when available. In many cases, specific gravity is given for the inner and outer bark, as well as the total bark.

Chemical Composition of Wood and Bark

Much information is available in the literature, particularly on the composition of wood, and not all of this information can be included if the book is to be kept to a reasonable size. Representative information is given, and the reader may utilize the literature cited to obtain more information.

Pulping

Descriptions of pulping processes have been kept brief and, again, the reader is encouraged to read the articles cited for more information.

EASTERN WHITE PINE

Scientific Name *Pinus strobus* L.

Synonyms White pine, northern white pine, northern pine, soft pine, Weymouth pine, cork pine

Family Name Pinaceae

Range Southern Canada, Lake States, Northeast, and the Appalachians. The eastern white pine type covers 7 million acres (2.8 million ha) in the Northeast (*1*).

Silvics The tree has a tall, clear, cylindrical bole, a crown composed of several nearly horizontal or ascending branches, and a wide-spreading, moderately deep root system without a taproot. Best development is made on moist, sandy loam soils, or those with a small proportion of clay. In Canada, pure stands or mixtures with red pine and red spruce frequently occur, whereas in the Northeast, in addition to limited pure groups, white pine occurs on sandy loams with the northern hardwoods, red spruce, and hemlock. Relatively little now grows in the Lake States where once magnificent stands flourished, but the species appears to be on the increase. Eastern white pine is rated as intermediate in tolerance.

Tree Dimensions The largest northeastern conifer, 80-100 ft (24-30 m) tall and 2-3.5 ft (61-107 cm) in diameter.

Pathology Resistance to decay: intermediate

By far the most important disease of eastern white pine is white pine blister rust (*Cronartium ribicola*). Because of this disease, management of white pine is limited to areas of low hazard. The heart rot fungus, *Phellinus pini,* is responsible for about 90% of the cull in eastern white pine and enters through branch stubs and weevil-killed shoots (*2*). Another destructive fungus of eastern white pine is *Stereum sanguinolentum.*

Two significant insect enemies of eastern white pine are the white pine weevil (*Pissodes strobi*) and the white pine sawfly (*Neodiprion pinetum*). The white pine weevil attacks the terminal shoot and affects tree form; the tree is seldom killed. Since the larvae of the sawfly feed on both old and new needles, complete defoliation of a tree is possible. The introduced pine sawfly (*Diprion similis*) favors white pine as a host, and heavily infested trees may be completely defoliated in one season.

Gross Features of the Wood The sapwood is white to pale yellowish white, and the heartwood is cream colored to light brown or reddish brown, turning much darker on exposure. The wood is moderately soft, light, medium textured, and has a slightly resinous noncharacteristic odor and no characteristic taste. Flat grain boards show a faint growth ring. Earlywood is usually wide, and the transition to latewood is gradual. In x-section the rays are very fine, not visible with the naked eye except where they include a horizontal resin canal, forming a fine, close, inconspicuous fleck on the r-surface.

Both horizontal and longitudinal resin canals are present. The longitudinal canals appear as whitish flecks with the naked eye, numerous, confined largely to the central and outer portions of the ring, solitary or rarely 2-3 contiguous in a tangential line, forming more or less prominent streaks along the grain. The horizontal canals appear as whitish, rather prominent wood rays, spaced at irregular intervals on the transverse surface. Parenchyma cells are absent. The dry weight of fiber in each of the components of white pine is covered in a publication by Young, et al. (*3*).

Microscopic Structure of the Wood

Tracheids. Average, 3.0 mm (1.6-5.0 mm) in length and 25-35 μm in diameter. Coarseness of 19.8 mg/100 m. Bordered pits in one row or occasionally paired on the radial walls, tangential pitting in the last few rows of latewood tracheids; pits leading to ray parenchyma are large, windowlike, 1-2 (generally 1) per crossfield; volume occupied, ca. 94%. Shepard and Bailey (*4*) reported that the average fiber length increased outward from the center of the tree and fluctuated widely in the outer rings. According to Fegel (*5*), root tracheids were longer than bole tracheids.

Resin Canals. Longitudinal, 90-120 μm in diameter, horizontal, less than 60 μm; thin-walled epithelial cells, frequently occluded with tylosoids in the heartwood; volume occupied, <1%.

Rays. Two types, uniseriate and fusiform; the uniseriate rays are numerous and 1-8+ cells high; the fusiform rays are scattered, with a horizontal resin canal, 2- to 3-seriate in the central portion, tapering to uniseriate margins, up to 30+ cells in height. Ray tracheids are present in both types of rays, marginal and interspersed, nondentate inner walls. Volume occupied, ca. 5%.

Gross Features of the Bark

On young stems thin and smooth, dark green, soon furrowed; on old trees 1-2 inches (2.5-5.0 cm) thick, broken into narrow, roughly rectangular blocks by deep, narrow fissures, minutely scaly on the surface; volume, ca. 12%. Bark thickness in similarly-aged portions of laterals increased with increasing height in the canopy (*6*). The bark of the merchantable bole accounted for 63% of the complete tree bark on a dry weight basis (*7*).

Microscopic Structure of the Bark (*8*)

Periderm. Broad and gently curving. Thin and thick-walled cells. Isolated zones of secondary phloem common between successive periderms.

Sclerenchyma. Absent in the secondary phloem.

Sieve Cells. Often in radial rows of about 10 cells; sieve areas often inclined to the vertical axis of the sieve cells.

Rays. Fusiform rays common, containing horizontal resin canals with well-defined borders.

Parenchyma. Often 1-3 parenchyma cells in a short radial multiple, forming rather irregular tangential lines on the cross section of the inner bark and containing crystals, small or large, but all with rectangular lateral faces. Other publications in this area include Abbe and Crafts (*9*) and Martin and Crist (*10*).

Physical Properties of Wood

Specific gravity	Green volume	0.34
	Air-dry volume	0.36
	Oven-dry volume	0.37
Density, lb/cu ft (kg/cu m)	Green	36 (577)
	Air-dry	25 (400)
	Oven-dry	23 (368)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	21 (336)

Up to 24% of variation in specific gravity was accounted for by variation in soil/site characteristics. Wood specific gravity increased with greater soil moisture storage capacity (*11*).

Geographic variation in specific gravity in Illinois showed specific gravity increased from N to S and from W to E (*12*).

Overall decrease in specific gravity with increase in height of tree (*13*).

Other publications on specific gravity of eastern white pine include Saucier and Taras (*14*), Lee (*15*), Gammon (*16*), Maeglin (*17*), Wahlgren, et al. (*18-19*).

Percent shrinkage, dried to 0% moisture content: r - 2.3, t - 6.0, v - 8.2

Percent moisture content, when green

Green basis	40
Oven-dry basis	68

According to Linzon (*20*), there is an increase in water content in late fall and early winter, drying out in late winter, slight increase in spring, fluctuations during summer strongly influenced by weather and a slight decrease in early fall.

Physical Properties of Bark

Specific gravity, green volume	Inner bark	0.32
	Outer bark	0.53
	Total bark	0.47
Specific gravity oven-dry weight & volume (*21*)		0.56
Density (100% moisture content)	Green weight/ green volume	1.01

Chemical Composition of Wood

Proximate Analyses.	Martin and Bray (*22*)	Ritter and Fleck (*23*) Sap	Ritter and Fleck (*23*) Heart	Skoggard and Libby (*24*)	Clermont and Schwartz (*25*)
Lignin, %	27.5	26.5	26.1	26.7	25.6
Holocellulose, %	–	–	–	–	66.6
C.&B. cellulose, %	60.0	54.3	50.2	57.2	–
Alpha-cellulose, %	44.0	29.6	28.8	–	48.1
Hemicellulose, %	–	–	–	–	14.13
Ash, %	–	0.23	0.42	0.19	0.18
Pentosans					
Total	10.6	9.31	8.56	7.84	5.82
In cellulose	–	6.8	7.1	–	–
Acetyl, %	–	1.68	1.43	–	1.15
Methoxyl, %	–	4.16	4.60	–	5.17
Solubility in					
Ether, %	3.0	5.46	3.62	2.65	5.88
Alcohol-benzene	6.9	–	–	6.01	–
1% NaOH	16.2	17.2	19.2	15.9	19.1
Cold water	–	3.55	5.97	3.47	3.26
Hot water	4.6	5.15	7.68	5.42	4.43
Moisture content	–	–	–	–	5.39
Uronic anhydride	–	–	–	–	3.25
In hemicelluloses					
Pentosans	–	–	–	–	26.0
Uronic anhydride	–	–	–	–	15.5
Hexosans (by difference)	–	–	–	–	58.5

Extractives. Contains 0.5% of pinosylvin monomethyl ether, 0.1% of chrysin, 0.1% of tectochrysin, 0.004% of pinostrobin, 0.07% of strobopinin, 0.3% of pinite, 0.08% of "membrane substances," and $C_{15}H_{12}O_5$ (possibly 2,3-dihydro-3-hydroxychrysin) (*26*, *27*) Tannins are absent (*28*). Small amounts of pectic substances have been isolated (*29*). For additional information on extractives see Drew and Pylant (*30*). For information on fatty acids and resin acids, see Swan (*31*).

Other Information. For elemental analysis see Young and Guinn (*32*) and Young et al. (*33*).

Chemical Composition of Bark

Proximate Analysis.

	Institute Paper Chemistry, Project 3212, Report 10
Solubility in Alcohol-benzene, %	15.5
Ash, %	1.2

Pulping

Kraft. The wood is readily reduced, yield is normal, and the pulp is strong; it is used for high-grade kraft wrapping papers and fiberboard (*40-42*).

Neutral Sulfite Semichemical. See Chidester (*43*).

Soda. The yield is normal (*42*). When sulfur was added to the cooking liquor, the resulting bleached pulp appeared to be a suitable substitute for the hardwood pulp common in the manufacture of book and like grades of paper (*44*).

Sulfite. Sapwood is readily reduced, while heartwood is reduced with difficulty. The yield is normal and the pulp is full greenish brown, shivy and harsh, and has excessive pitch. The use is limited by the dark color, shiviness, and hardness (*40, 45*).

Utilization of Wood and Bark

Use properties of wood. The freshly cut wood has a slightly resinous odor. The wood has a comparatively uniform texture, is easy to work with tools, has little shrinkage, is easily kiln-dried, ranks high in ability to stay in place, can be readily glued, and is straight-grained. It does not split easily in nailing and has an intermediate position in nail-holding ability. It is light in weight, moderately soft, moderately weak, not stiff, and ranks low in resistance to shock. The wood takes and holds paint excellently. It is intermediate in decay resistance.

Calorific value of wood.

millions of Btu/air-dry cord 17.1
millions of kcal/air-dry cord 4.3
heating value 6394 Btu/lb air-dry
3553 kcal/kg air-dry

Other uses of wood. Most of the wood that is harvested is for lumber. Most of the wood is used for boxes. High-grade wood is used for patterns for castings. Other leading uses are sash, doors, finish, trim, caskets and burial boxes, shade and map rollers, toys, dairy and poultry supplies, and boot and shoe findings. The wood flour is excellent for linoleum and plastic materials.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 445, 1973, 114 p.
2. Ohmann, L. F., Batzer, H. O., Buech, R. R., Lothner, D. C., Perala, D. A., Schipper, A. L., Jr. and Verry, E. S. USDA, Forest Serv. Gen. Tech. Report NC-48, 1978, 34 p.
3. Young, H. E., Hoar, L. and Ashley, M. Tappi 48(8): 466-9 (1965).
4. Shepard, H. B. and Bailey, J. W. Proc. Soc. Am. For. 9:522-5(1914).
5. Fegel, A. C. N.Y. State Coll. For., Tech. Bull. 55, 1951, 20 p.
6. Harmon, D. M. and Brown, M. L. Chesapeake Sci. 15(1): 30-8(1974).
7. Young, H. E. Forest Prod. Jour. 21(5):56-9 (1971).
8. Chang, Y. P. USDA, Tech. Bull. Bull. No. 1095, 1954, 86 p.
9. Abbe, L. B. and Crafts, A. S. The Botanical Gazette 100(4):695-722(1939).
10. Martin, R. E. and Crist, J. B. Wood Fiber 2(3): 269-79(Fall, 1970).
11. Thor, E. and Bates, A. L. Jour. Tenn. Acad. Sci. 48(1):5-9(1973).
12. Gilmore, A R. Forest Prod. Jour. 18(11):49-51 (1968).
13. Okkonen, E. A., Wahlgren, H. E. and Maeglin, R. R. Forest Prod. Jour. 22(7):37-42(1972).
14. Saucier, J R. and Taras, M. A. USDA, Forest Serv. Res. Pap. SE-45, 1969, 16 p.
15. Lee, C. H. Proc. 21st Northeastern For. Tree Improve. Conf.: 36-41(1974).
16. Gammon, G. L. USDA, Forest Serv. Res. Note NE-99, 1969, 6 p.
17. Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-202, 1973, 40 p.
18. Wahlgren, H. E., Hart, A. C. and Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-61, 1966, 22 p.

19. Wahlgren, H. E., Baker, G., Maeglin, R. R. and Hart, A. C. USDA, Forest Serv. Res. Pap. FPL-95, 1968, 12 p.

20. Linzon, S. N. For. Chron. 45(1):38-43(1969).

21. Harkin, J M. and Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.

22. Martin, J. S. and Bray, M. W. Tech. Assoc. Papers 24:596 (1941); Paper Trade J. 111 (25) 35 (Dec. 19, 1940).

23. Ritter, G. J. and Fleck, L. C. Ind. Eng. Chem. 15:1055 (1923).

24. Skoggard, C. O. and Libby, C. E. Tech. Assoc. Papers 29:479(1946); Paper Trade J. 123(4):41(July 25, 1946).

25. Clermont, L. P. and Schwartz, H. Pulp Paper Mag. Can. 52(13):103-5(Dec., 1951).

26. Erdtman, H. Svensk Papperstidn. 46:226(1943).

27. Erdtman, J Svensk Kem. Tid. 56:2(1944).

28. Russell, A. J Am. Leather Chemists Assoc. 37:340 (1942).

29. Anderson, E., Seigle, L. W., Krznarich, L. R. and Marteny, W. W. J. Biol. Chem. 121:165(1937).

30. Drew, J and Pylant, G. D., Jr. Tappi 49(10): 430-8 (Oct., 1966).

31. Swan, E. P. Can. Dept. Forestry, Inform. Rept. VP-X-115:24 p. (Aug., 1973).

32. Young, H. E. and Guinn, V. P. Tappi 49(5): 190-7 (May, 1966).

33. Young, H. E., Carpenter, P. N. and Altenberger, R. A. Maine Agricultural Experiment Station, Tech. Bull. 20(Oct., 1965). 88 p.

34. Young, H. E. Forest Products J. 21(5): 56-59(May, 1971).

35. Harder, M. L. and Einspahr, D. W. To be submitted to Tappi.

36. Forest Products Laboratory. Tech. Note No. 191. Dec., 1939. 3 p.

37. Running, K. D. Pulp Paper Mag. Canada 41(2): 181 (1940).

38. Schafer, E. R. and Hyttinen, A. Paper Trade J. 129, No. 11:37(1949).

39, Thickens, J. H. and McNaughton, G. C. U.S. Dept. Agr., Bull. 343. (1916).

40. Wells, S. D. and Rue, J. D. U.S. Dept. Agr., Dept. Bull. 1485. (May, 1927). 101 p.

41. Brayy, M. W. and Curran, C. E. Paper Trade J. 97(5): 30(Aug. 3, 1933).

42. Forest Products Laboratory. Tech. Note No. 191. (Dec., 1939). 3 p.

43. Chidester, G. H. Proc. Forest Products Research Soc. 3:197(1949).

44. Bray, M. W., Martin, J. S. and Carpenter, L. A. Tech. Assoc. Papers 14:214 (1931); Paper Trade J. 93(12): 33-38(Sept. 17, 1931).

45. Skoggard, C. O. and Libby, C. E. Tech. Assoc. Papers 29:479(1946); Paper Trade J. 123(4):41(July 25, 1946).

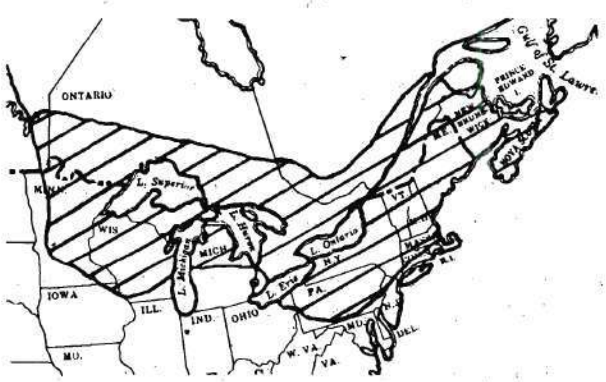
RED PINE

Scientific Name *Pinus resinosa* Ait.

Synonyms Norway pine

Family Name Pinaceae

Range Southern Canada, Lake States and Northeast, in a relatively narrow zone about 1,500 mi (2400 km) long and 500 mi (800 km) wide around the Great Lakes and the St. Lawrence River (*1*). The species covers about 1 million acres (405,000 ha) in the Lake States (*2*).



Silvics The tree has a symmetrical oval crown, a well-formed, long, cylindrical bole, and a spreading root system with a poorly developed taproot. Formerly, magnificent pure and mixed stands grew on sandy soils in the Lake States. Now, on cutover lands, this species appears to be following jack pine and is often found in mixture with it. It grows chiefly on areas where the soil is acid and has good drainage and aeration. Where it is abundant in the Lake States and Ontario, red pine grows most commonly on level or gently rolling sand plains or on low ridges adjacent to lakes and swamps, at elevations from 800 to 1400 ft above sea level. Paper birch, gray birch, and aspen are sometimes in mixture with red pine in young stands. Although seeds may be produced each year, good crops occur only at intervals of 3-7 years. The species is rated as intolerant.

Tree Dimensions Medium-sized to large tree; 50-80 ft (15-24 m) tall and 2-3 ft (61-91 cm) in diameter.

Pathology Resistance to decay: low

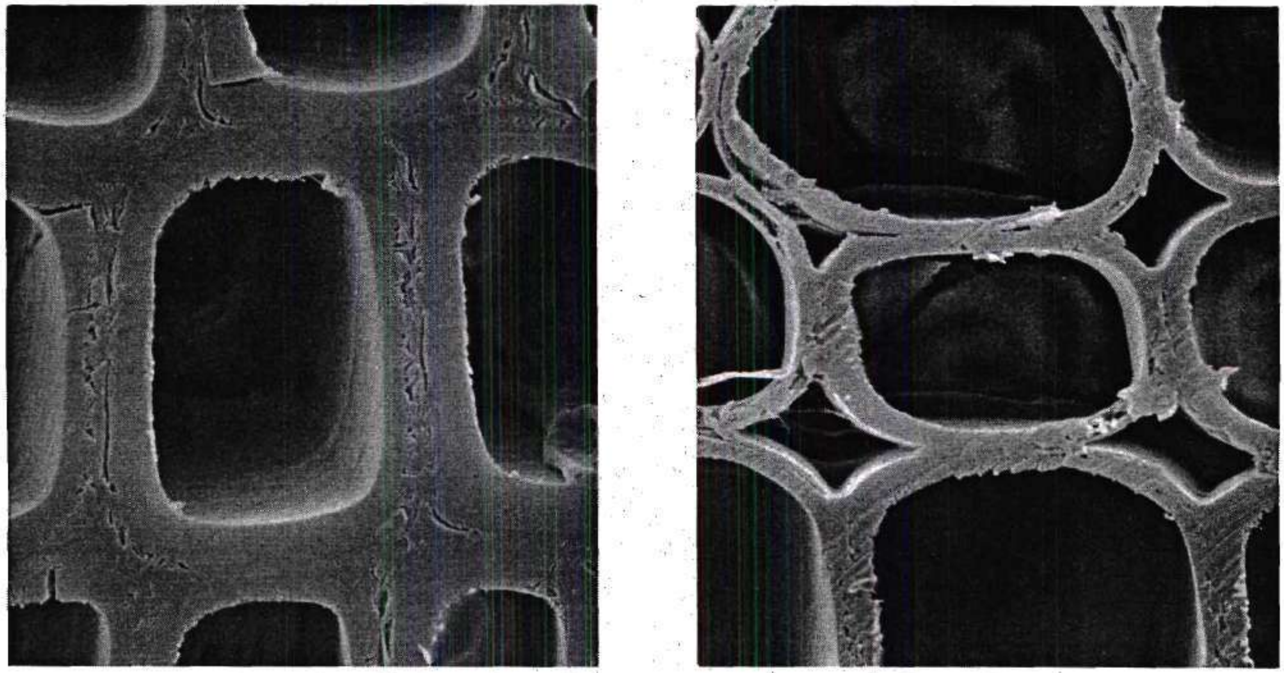
A disease of great concern in red pine plantations is scleroderris canker (*Scleroderris lagerbergii*). Red pine has proven to be very susceptible to this dieback and canker disease and, because of its lack of genetic variability, no resistant strains appear to exist. Another serious disease of red pine is the needlecast fungus, *Lophodermium pinastri*, which can cause great mortality in nurseries and plantations. However, the trees appear to acquire resistance to the fungus as they get older. Red pine is also subject to several rots including white stringy root rot (*Heterobasidion annosum*), red heart rot (*Phellinus pini*) and red-brown butt rot (*Phaeolus schweinitzii*). Red pine shoot blight is an important disease of red pine reproduction.

The pine tussock moth (*Dasychira pinicolor*) is a serious pest of foliage and is capable of completely defoliating trees. The Zimmerman pine moth (*Dioryctria zimmermani*) bores inside the base of the terminal shoot, lateral shoots, or any branches. The European pine shoot moth (*Rhyacionia buoliana*) is one of the most destructive shoot-boring moths, with seedlings and young planted saplings being the most susceptible to it. The Nantucket pine tip moth (*Rhyacionia frustrana*) is another major pest of young trees. The white pine weevil (*Pissodes strobi*) attacks the terminal growth of red pine. The Saratoga spittlebug (*Aphrophora satatogensis*) kills sapling pines.

Gross Features of the Wood The sapwood is white to yellowish, and the heartwood is light red to orange brown or reddish brown. The wood is moderately soft and moderately heavy, medium textured, straight and even grained, and has a fairly strong, resinous, noncharacteristic odor, without a characteristic taste. The earlywood zone is generally wide; the transition from earlywood to latewood is more or less abrupt; the latewood zone is narrow to fairly wide, darker and appreciably denser than the earlywood zone. Flat-grain boards exhibit a distinct, inconspicuous growth ring. In the x-section the rays are very fine, not visible with the naked eye, appearing whitish with a lens where they contain a horizontal resin canal, and forming a fine, close, inconspicuous fleck on the radial surface. Both longitudinal and horizontal resin canals are present. The longitudinal canals are relatively inconspicuous with the naked eye, appearing as minute, brownish flecks, relatively conspicuous with a hand lens, numerous, confined largely to the central and outer parts of the growth ring, solitary or rarely 2-3 contiguous in a tangential line, not visible or forming relatively inconspicuous streaks along the grain. The horizontal canals are less conspicuous than the longitudinal canals, appearing as whitish, radial lines spaced at irregular intervals on the transverse surface. Longitudinal parenchyma cells are absent. Zahner, et al. (*3*) discuss the earlywood-latewood features of red pine grown under simulated drought and irrigation. Described by Whitmore and Zahner is the development of the xylem ring in young red pine (*4*).

ing irrigation (*5*).

According to a study by Larson (*6*), the influence of drought was directly on the growth of the terminal meristems and only indirectly on tracheid diameter through the intermediate action of auxin.



Scanning electron micrograph of red pine, showing summerwood normal wood (left) and springwood compression wood (right). The compression wood exhibits the typical rounded tracheids with intercellular spaces. Part of a bordered pit can be seen at the top of the center fiber in photograph on the right. Magnification, 2200X (left) and 1800X (right).

Microscopic Structure of the Wood

Tracheids. Average, 3.4 mm in length (1.2-5.2 mm) and 30-40 μm in diameter. The weight factor (unbleached kraft) is 0.90 and coarseness is 21.4 mg/100 m. Bordered pits in 1, or occasionally 2, rows on the radial walls; tangential pitting absent or very sporadic in the last few rows of latewood tracheids; pits leading to ray parenchyma large, windowlike, 1-2 (usually 1) per ray crossing; ray tracheid pits small and uniform in size. When red pine was irrigated with municipal wastewater for 4 years and compared to untreated trees or the same tree prior to irrigation, stem wood tracheid length was found to be unaffected by treatment. However, decreased cell wall thicknesses occurred in tracheids from wood grown during irrigation (*5*).

Resin Canals. Longitudinal, 80-110 μm in diameter; horizontal, usually less than 50 μm; thin-walled epithelial cells; frequently occluded with tylosoids in the heartwood.

Rays. Two types, uniseriate and fusiform; the uniseriate rays are numerous and 1-15 cells (333 μm) in height; the fusiform rays are scattered and contain a horizontal resin canal, 2- to 3-seriate in the central portion, tapering to uniseriate margins, up to 23 cells (422 μm) in height. Ray tracheids are present in both types of rays, marginal and interspersed, shallowly dentate inner walls. Four rays per mm tangentially on the x-section; 21-25 rays per sq. mm. on the tangential surface. Volume occupied, approximately 7%.

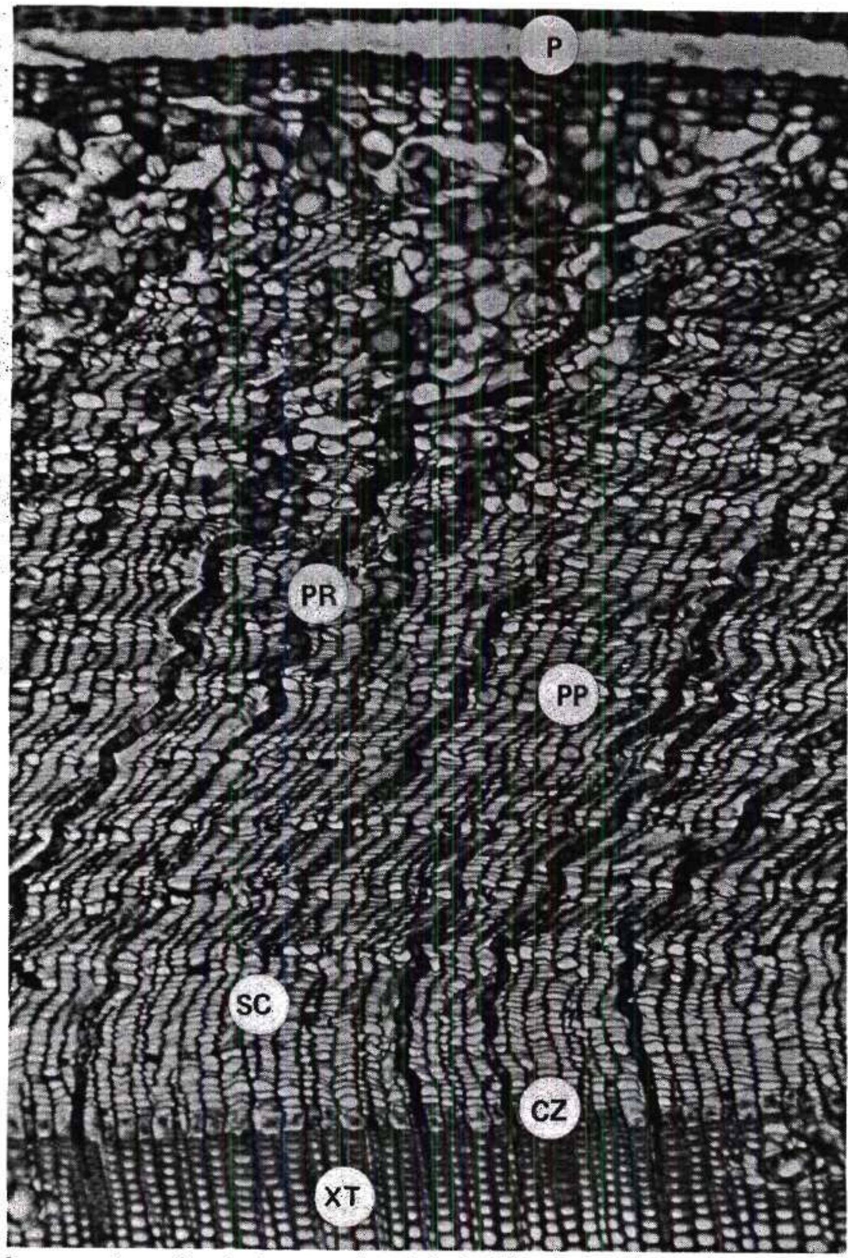
Gross Features of the Bark Flaky and orange red on young trees, eventually breaking up into large, flat, reddish-brown, superficially scaly plates irregularly diamond shaped in outline.

Microscopic Structure of the Bark

Rhytidome. Remnants of the phloem lie to the outside of the last-formed periderm, mixed with expanded parenchyma cells which occupy much of the area between periderms.

Periderm. A periderm layer is composed of 2-3 layers of phelloderm, a layer of phellogen, and a number of thin-walled phellem cells that usually alternate with several layers of thick-walled phelem cells.

Secondary Phloem. This is composed of sieve cells, lon-



Cross section of red pine wood and bark. Elements depicted include xylem tracheids (XT), cambium zone (CZ), sieve cells (SC), phloem parenchyma (PP), phloem ray (PR) and a periderm (P). Magnification, 75X.

gitudinal strands of phloem parenchyma and phloem rays with marginal albuminous cells. The sieve cells are aligned in radial rows of 6-8 cells, sometimes up to 10 cells in a continuous row. These types of cells are interrupted by parenchyma arranged in short radial rows of 1-3 cells aligned more or less tangentially in continuous lines in cross section. Styloid crystals, composed of calcium oxalate, were evident (tangential section) in many of the phloem parenchyma cells.

Sieve Cells. Uncollapsed sieve cells near the cambium zone are rectangular in cross section and average 30-40 μm tangentially and 20-30 μm radially.

Parenchyma. Parenchyma cells are about the same in cross-sectional area as sieve cells but are more oval and slightly broader radially.

Rays. Of two sizes, uniseriate and fusiform. Uniseriate rays are comparatively low, mostly 8 or fewer cells or about 20 μm. Fusiform rays containing horizontal resin canals are usually less than 100 μm wide and 300-400 μm high on tangential section.

Sclerenchyma. Absent in the secondary phloem. Some phellem cells in the periderm sclerify and become stone cells. These types of cells have irregular projections at their margins and interlock with adjacent cells in a cog-like manner. Individual cells are small (av. diam. $<$100 μm).

Physical Properties of Wood

Specific gravity	Green volume	0.39
	Air-dry volume	0.48
	Oven-dry volume	0.51
Density, lb/cu ft (kg/cu m)	Green	42 (673)
	Air-dry	34 (545)
	Oven-dry	32 (513)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	27 (432)

Gilmore (*7*) reported that specific gravity of red pine in plantation-grown trees in Illinois increased from north to south.

Overall decrease in specific gravity with increase in height of tree (*8*).

According to Gray and de Zeeuw (*9*), density of the wood in both earlywood and latewood was shown to be decreased by treatment of the site with potassium. The density changes were shown to be related to changes in tracheid dimension. A bibliography dealing with the effect of fertilization on wood quality has been compiled by Clemson University, Department of Forestry (*10*).

Other publications on specific gravity of red pine include Baker (*11*), Cody (*12*), Maeglin (*13-14*), Pronin (*15*), Wahlgren, et al. (*16-17*), and Baker and Shottafer (*18*).

Percent shrinkage, dried to 0% moisture content: r - 4.6, t - 7.2, v - 11.5 (*19*).

Percent moisture content, when green	
Green basis	35
Oven-dry basis	54

Percent moisture content, oven-dry basis (*19*)	
Heartwood	32
Sapwood	134

Moisture content, based on green weight (*20*)	
Bolewood	50.9
Topwood	59.6

Physical Properties of Bark

Specific gravity, green volume	Inner bark	0.20
	Outer bark	0.29
	Total bark	0.27
Density (100% moisture content)	Green weight/ green volume	0.62
Specific gravity, oven-dry weight & volume (*21*)		0.32

Moisture content, based on green weight (*20*)	
Bole bark	55.1
Top bark	61.6

Chemical Composition of Wood

Proximate Analyses.	Clermont and Schwartz (*23*)	F.P.L. (*24*)
Lignin, %	23.40[a]	26.2
Holocellulose, %	67.3[b]	71.3

Alpha-cellulose, %	47.80[c]	46.8
Hemicelluloses, %	15.11[a]	—
Ash, %	0.23	—
Pentosans, %	7.97	10.0
Acetyl, %	1.87	—
Methoxyl, %	4.51	—
Solubility in		
Alcohol-benzene, %	—	3.5
Ether, %	8.24	2.5
1% NaOH, %	21.41	13.4
Hot water, %	5.18	4.4
Cold water, %	2.71	—
Uronic Anhydride	3.14	—
In Hemicelluloses		
Pentosans	37.3[d]	—
Uronic Anhydride	15.6[d]	—
Hexosans (by difference)	47.1[d]	—

[a]corrected for ash
[b]corrected for extractives, ash and lignin
[c]corrected for lignin and ash
[d]as % of moisture-free hemicellulose

Extractives. For information on extractives see Drew and Pylant (*25*).

The volatile oil from the wood, d^{20} 0.8636, η^{20} 1.4713, $[\alpha]_D$ 17.4°, contains pinene. This oil is not identical with that from oleoresin (*26-27*).

Other information. For information fatty acids and resin acids see Swan (*28*).

Chemical Composition of Bark

Proximate Analyses.

	Institute Paper Chemistry, Project 3212, Report 6
Ash	1.3%
Calcium	0.3%
Silica	0.03%
Alcohol-benzene extractives	5.8%

Pulping

Kraft. Is readily reduced and is strong; the yield is normal (*29*).

Neutral Sulfite Semichemical. Chidester (*30*) has studied the effect of acid, neutral, and alkaline pretreatment and bleaching on yield and mechanical properties.

Oxygen-alkali. Use of a two-stage process using oxygen in both stages produces pulps in low yield equivalent in strength to kraft pulps. The oxygen pulps also are more rapidly beaten and produced denser sheets than the kraft pulps (*31*).

Sulfite. Young trees and sapwood are reduced readily; yield is normal, and pulp is pitchy, fairly strong, and of good color. The pulp is fairly easily bleached. Pulp prepared from mature wood contained a very large amount of pitch (*29, 31*).

Utilization of Wood and Bark

Use properties of wood. The wood is moderately heavy, moderately strong in endwise compression strength, stiff, moderately soft, and moderately high in shock resistance. It is generally straight-grained, is somewhat resinous, and has a resinous odor. The lumber has moderately large shrinkage when dried and is not difficult to air-dry or kiln dry without checking or warping. It stays in place well when properly seasoned. It rates below eastern white pine in ease of working with tools and is about the same in nail-holding ability.

Calorific value of wood.
millions of Btu/air-dry cord: 19.7
millions of kcal/air-dry cord: 5.0

Calorific value of bark.
Btu/oven-dry lb. 9070
kcal/kg 5039

Other uses of wood. The wood is used for particle boards and hardboards.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 271, 1965, 762 p.
2. USDA, Forest Service. Agriculture Handbook No. 445, 1973, 114 p.

3. Zahner, R., Lotan, J. E. and Baughman, W. D. Forest Sci. 10(3): 361-70 (1964).

4. Whitmore, F. W. and Zahner, R. Forest Sci. 12(2): 198-210 (1966).

5. Murphey, W. K., Brisbin, R. L. and Binotto, A. P. The Pennsylvania State University, College of Agriculture, Bull. No. 789, 1973, 21 p.

6. Larson, P. R. Forest Sci. 9(1):52-62 (1963).

7. Gilmore, A. R. Forest Prod. Jour. 18(11): 49-51 (1968).

8. Okkonen, E. A., Wahlgren, H. E. and Maeglin, R. R. Forest Prod. Jour. 22(7):37-42(1972).

9. Gray, R. L. and de Zeeuw, C, In Proc. 22nd Northeastern Forest Tree Improvement Conf., Syracuse, NY, 1974, pp. 72-84.

10. Clemson University, Dept. of Forestry. Forest Research Series No. 29, 1974.

11. Baker, G. Forest Prod. Jour. 17(8):21-4 (1967).

12. Cody, J. B. State University of New York, AFRI Res. Report No. 9, 1972, 19 p.

13. Maeglin, R. R. USDA, Forest Serv. Res. Note FPL-0149, 1966, 14 p.

14. Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-202, 1973, 40 p.

15. Pronin, D. USDA, Forest Serv. Res. Pap. FPL-161, 1971, 16 p.

16. Wahlgren, H. E., Hartland, A. C. and Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-61, 1966, 22 p.

17. Wahlgren, H. E., Baker, G., Maeglin, R. R. and Hart, A. C. USDA, Forest Serv. Res. Pap. FPL-95, 1968, 12 p.

18. Baker, G. and Shottafer, J. E. USDA, Forest Serv. Res. Pap. NC-23, 1968, 60 p.

19. USDA, Forest Service. Forest Prod. Laboratory. Agriculture Handbook No. 72, 1974.

20. Erickson, J. R. USDA, Forest Serv. Res. Note NC-141, 1972, 3 p.

21. Harkin, J. M. and Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.

22. Lamb, F. M. and Marden, R. M. Forest Prod. Jour. 18(9):77-82 (1968).

23. Clermont, L. P. and Schwartz, H. Pulp Paper Mag. Can. 53(6):142 (May, 1952).

24. Forest Products Laboratory. Unpublished data.

25. Drew, J. and Pylant, G. D., Jr. Tappi 49(10): 430-8 (Oct., 1966).

26. Frankforter, G. B. J. Am. Chem. Soc. 28:1467 (1906).

27. Frankforter, G. B. J. Am. Chem. Soc. 31:561 (1909).

28. Swan, E. P. Can. Dept. Forestry, Inform. Rept. VP-X-115: 24 p. (Aug., 1973).

29. Wells, S. D. and Rue, J. D. U.S. Dept. Agr., Dept. Bull. 1485. May, 1927. 101 p.

30. Chidester, G. H. Forest Products Research Soc. 3:197(1949).

31. Marton, R. and Leopold, B. Appita 27(2):112-18 (Sept., 1973).

32. Studeny, J. and Libby, C. E. Tech. Assoc. Papers 23:582(1940); Paper Trade J. 109(20):29(Nov. 16, 1939).

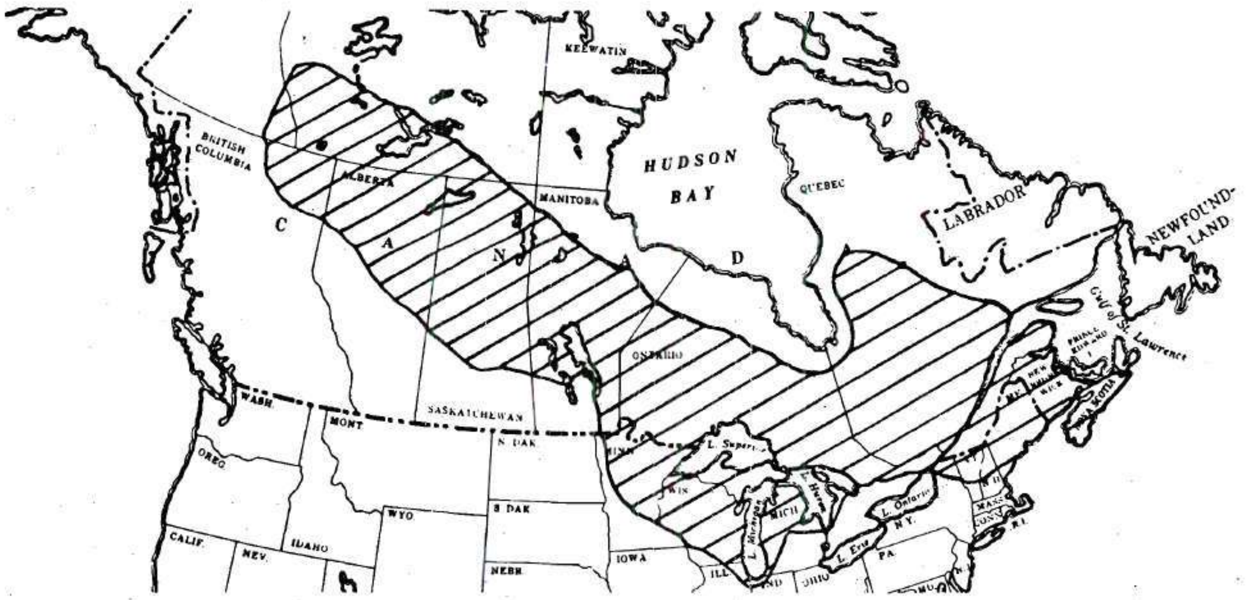
JACK PINE

Scientific Name *Pinus banksiana* Lamb.

Synonyms Scrub pine, gray pine, black pine, Banksian pine.

Family Name Pinaceae

Range Canada, Lake States and northern New England. The species grows farther north than any other American pine (*1*) and is found on more than 2 million acres (810,000 ha) in the Lake States (*2*).



Silvics Jack pine is a short-lived, small-to-medium-sized tree which can endure extremely cold climates. The tree has a scraggly appearance and has poor natural pruning. The root system is widespreading and moderately deep. Jack pine can maintain itself on very dry sandy or gravelly soils where other species scarcely can survive. Best growth is made on fairly deep, moist soil with good drainage but it is usually crowded out of such locations by species requiring less sunlight. This species is a pioneer tree and occurs in pure stands or in open mixtures with aspen and white birch or scrub oak on dry sandy soils. Farther north black spruce may be a common associate. Red pine and eastern white pine are frequent associates of jack pine and eventually replace it. Some cones are produced annually; many of them persist on the tree for several years before they finally become sufficiently dried by wind and sun or fire heat to open and distribute their seed. The species is rated as very intolerant.

Tree Dimensions Can grow to 70-80 ft (21-24 m) tall and 12-15 in (30-38 cm) in diameter but is usually much smaller. At 60 years of age on a medium site, jack pine averaged 60 ft (18 m) in height and 8.8 in (22.4 cm) in diameter (*1*).

Pathology Resistance to decay: intermediate.

Dwarf mistletoe (*Arceuthobium americanum*) is a serious pest of jack pine in Canada. Jack pine is also attacked by a number of rusts including sweetfern rust (*Cronartium comptoniae*), eastern gall rust (*Cronartium quercuum*), stalactiform rust (*Peridermium stalactiforme*) and western gall rust (*P. harknessii*). Rots affecting jack pine include *Heterobasidion annosum* and *Phellinus pini*.

Although the jack pine sawfly (*Neodiprion pratti banksianae*) attacks all sizes of trees, small trees with open crowns are the most susceptible. Mortality seldom occurs from a single defoliation but may result from successive defoliations. The jack pine budworm (*Choristoneura pinus*) causes top killing and stagheadedness. Outbreaks last 2-4 years. The Saratoga spittlebug (*Aphrophora saratogensis*) kills sapling pines. The white-pine weevil (*Pissodes strobi*) larvae feed on inner bark and outer wood while the adults feed on both old and mature new growth.

Gross Features of the Wood

The sapwood of jack pine is white with a yellowish tinge, and the heartwood has a reddish tinge. The wood is moderately soft, moderately heavy, and medium textured. It has a distinct, resinous, noncharacteristic odor, and not characteristic taste. The earlywood zone is usually much wider than the darker-colored latewood; the transition is more or less abrupt. Flat sawn boards exhibit a distinct but not conspicuous growth ring. In the x-section the rays are very fine, not visible with the naked eye, and form a fine, close, inconspicuous fleck on the quarter surface. Both longitudinal and horizontal resin canals are present and relatively inconspicuous with the unaided eye. The longitudinal canals are numerous, confined for the most part to the central and outer portions of the growth ring, mostly solitary, forming inconspicuous, brownish streaks along the grain. The horizontal canals are inconspicuous, appearing with a hand lens as whitish, radial lines spaced at irregular intervals on the x-section, barely visible with a lens on the t-section. Parenchyma cells are absent.

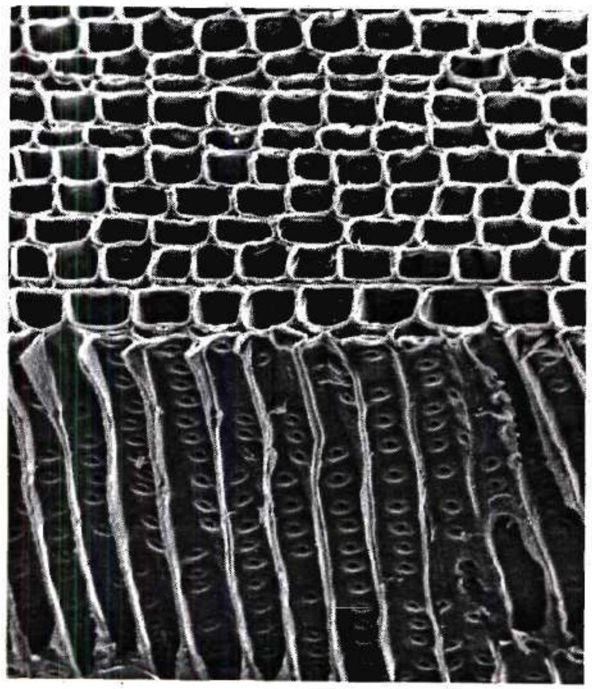
Microscopic Structure of the Wood

Tracheids. Average, 3.5 mm (1.5-5.7 mm) in length and 28-40 μm in diameter. Weight factor (unbleached kraft) is 0.90 and coarseness is 18.0 mg/100 m. Fiber walls are relatively thick. Fiber dimensions for juvenile jack pine grown under intensive culture are covered in a paper by Crist, et al. (*3*). According to Kribs (*4*), latewood tracheids are in most cases somewhat longer than those in earlywood.

Resin Canals. Longitudinal, 75-90 μm in diameter; horizontal canals less than 45 μm; thin-walled epithelial cells; tylosoids present in the heartwood.

Rays. Two types, uniseriate and fusiform; uniseriate rays numerous, up to 27 cells (562 μm) high; fusiform rays scattered, 2- to 3-seriate in the central portion, tapering to uniseriate margins, up to 29 cells (575 μm) in height. Ray tracheids both marginal and interspersed, the interspersed usually being found in the higher rays; shallowly dentate inner walls. Five rays per mm tangentially on the x-section and 27 per sq mm on the tangential surface.

Longitudinal Parenchyma. Absent.



Scanning electron micrograph of jack pine, showing cross-sectional and radial views. Illustrated are border pits which, unlike in most conifers, are predominantly on the radial walls of the fibers. Magnification, 155X

Gross Features of the Bark

Dull brown with a yellowish hue on the outer surface, the relatively thin jack pine bark forms small scales and narrow furrows. Narrow layers of pinkish-yellow periderm and deep reddish-brown secondary phloem with abundant resin canals appear in the outer bark. The inner bark is very narrow and about the same width as the rhytidorne layers. According to Marden, et al. (*5*), bark averaged 3.9% by weight of the total green wood-bark weight. Bark thickness is also covered in a publication by Hale (*6*).

Microscopic Structure of the Bark.

Rhytidome. The formation of the narrow and numerous rhytidome layers involves the expansion of parenchyma and ray cells in the inner and outer bark, and the development of the thin and alternately thick, heavily lignified phellem cells in the periderm. Isolated by the successive periderm layers, the secondary phloem tissues in the rhytidome are in great contrast to those of the inner bark because of the expanded parenchyma, crushed sieve cells and numerous resin canals.

Periderm. The rather broad periderm is composed of a layer of phellogen, alternate layers of thin and thick-walled phellem and 4-7 layers of phelloderm. Phellem and phelloderm cells, rectangular on cross section, are about the same size and shape, mostly 30-40 μm and about 20 μm on tangential and radial dimensions, respectively (7).

Inner Bark. Composed of sieve cells, phloem parenchyma and both uniseriate and fusiform rays.

Sieve Cells. Radially aligned, rectangular on cross section and variable in size. Usually 15 ± 10 μm in radial diameter and 35 ± 15 μm in tangential diameter with an average length of 1.2-3.0 mm. Cell walls are cellulosic and appear to show distinct secondary wall thickenings. Interrupting every 11-19 cells in a radial row are single-layered lines of parenchyma. Sieve cells account for approximately 80% of the tissue elements of the secondary phloem (7).

Sclerenchyma. Absent in the secondary phloem.

Parenchyma. On cross section, parenchyma cells close to the cambial area are similar in size and shape to the adjacent sieve cells, but they quickly expand and occupy most of the secondary phloem region. Individual cells are usually 70-150 μm in height, and a parenchyma strand is about the same length as the neighboring sieve cells.

Rays. Uniseriate rays are generally 10 cells or 200-300 μm in height with erect ray marginal, or albuminous cells, 2-3 times the height of regular ray cells, in all rays close to the cambium. Fusiform rays contain horizontal resin canals lined by 3-4 thin-walled epithelial cells.

Physical Properties of Wood

Specific gravity	Green volume	0.39
	Air-dry volume	0.43
	Oven-dry volume	0.46
Density, lb/cu ft (kg/cu m)	Green	50 (801)
	Air-dry	30 (481)
	Oven-dry	29 (464)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	24 (384)

Grigal and Sucoff (8) reported that, as the distance to the crown increased (measured from the ground to the lowest green branch), the proportion of earlywood decreased and the specific gravity of the wood increased. Other publications relating to specific gravity include Erickson (*9*), King (*10*), Maeglin (*11*), Pronin (*12*) and Wilde and Voigt (*13*).

Percent shrinkage, dried to 0% moisture content (*14*): r - 3.4, t - 6.5, v - 10.4.

Percent moisture content, when green

Green basis	51
Oven-dry basis	105

Physical Properties of Bark

Specific gravity, green volume	Inner bark	–
	Outer bark	0.43
	Total bark	0.41
Density (100% moisture content)	Green weight/ green volume	0.83

Additional publications on bark specific gravity include Hale (*6*) and Lamb and Marden (*15*).

Percent moisture content, based on green weight (*9*).

Bole bark	54.9
Top bark	65.6

Another publication on moisture content of jack pine is by Marden, et al. (*5*).

Chemical Composition of Wood

Proximate Analyses.

	F.P.L.	F.P.L. (*16*)	Clermont and Schwartz (*17*)
Lignin, %	29.9	26.7	27.38[a]
Holocellulose, %	–	62.3	68.0[b]
C.&B. cellulose, %	58.3	–	–
Alpha-cellulose, %	42.8	45.2	47.52[c]
Hemicellulose	–	–	16.18[a]
In hemicelluloses			
Pentosans	–	–	33.7[d]
Uronic anhydride	–	–	15.0[d]
Hexosans (by difference)	–	–	51.3[d]
Ash, %	–	0.3	0.19
Pentosans			
Total, %	14.0	9.7	10.13
In cellulose, %	–	9.3	–
Acetyl	–	–	1.08
Methoxyl	–	–	4.97
Solubility in			
Ether, %	2.4	2.3	4.30

Alcohol-benzene, %	4.2	3.7	–
1% NaOH, %	13.9	11.2	16.3
Hot water, %	3.1	2.9	–
Moisture content	–	–	6.64
Lignin (corrected for ash)	–	–	27.38
Uronic anhydride	–	–	3.67

[a]Corrected for ash.
[b]Corrected for ash, lignin, and extractives.
[c]Corrected for ash and lignin.
[d]Results expressed as % of the moisture-free hemicelluloses.

Barnes (*18*) found the solubility in ether to be 2.4-3.2% and solubility in alcohol-benzene to be 3.1-4.9%. Mingle and Boubel (*19*) found the ash content to be 2.1%, volatile matter 74.3%, and fixed carbon 23.6%.

In addition, Chidester, Bray, and Curran (*20*) have reported analyses on top, middle, and butt logs from the same tree; Chidester and McGovern (*21*) compared sap and heart analyses; and Hajny and Ritter (*22*) gave data on holocellulose and C.&B. cellulose.

Extractives. For information on resin acids and fatty acids see Swan (*23*). For information on extractives see Sinclair and Dymond (*24, 25*), Chapman, et al. (*26*), Hibbert and Phillips (*27*), Buchanan, et al. (*18*), Drew and Pylant (*28*).

Resins from green and seasoned wood have been studied. The extractives from seasoned wood contained less fats and more resin acids. The fatty acids are largely unsaturated. A phytosterol, m.p. 131-2°, was found, together with resenes and polymerized terpenes (*27*).

Pinosylvin monomethyl ether; 2,3-dihydrochrysin; $C_{15}H_{12}O_5$ (possibly 2,3-dihydro-3-hydroxychrysin); and arabinose have been reported (*29*); also pinocembrin and pinobanksin (*30*). Arabogalactan has been found in the water extractives (*31*).

Chemical Composition of Bark

Proximate Analyses.

	Chang and Mitchell (*32*)	Institute Paper Chemistry, Project 3212, Report 5	Milliken (*33*)
Solubility in Benzene, %	8.0	–	–
95% alcohol, %	12.4	–	–
Hot water, %	3.0	–	–
1% NaOH	41.3	–	–
Methoxyl, %	3.07	–	–
Ash, %	1.7	1.3	2.1
Calcium content	–	0.3	–
Silica content	–	0.14	–
Solubility in Alcohol-benzene, %	–	15.3	–
Volatile, %	–	–	74.3
Fixed carbon	–	–	23.6

Carbohydrates. For reducing sugars from extractive-free bark, see Chang and Mitchell (*32*).

Other Information. For an ultimate analysis of bark, see Milliken (*33*); he found the ash content to be 2.0%.

Pulping

Ammonium bisulfite. This process can be used; for information see Detcher and Jones (*34*) and Stevens (*35*).

Calcium bisulfite. This process is not suitable, especially if a high percentage of heartwood is present (*34*).

Groundwood. Groundwood from chips makes excellent pulp with high brightness and excellent strength characteristics (*36*). It can be bleached by a two-stage process of H_2O_2 followed by ZnS_2O_4. For information on bleaching see Wayman, et al. (*37*). The wood is reduced fairly readily to a pulp of gray color and standard strength in a yield of about 89%. It usually leads to excessive pitch in the papermaking phase. It requires 40-50% more power than white spruce. Knots and heartwood are common (*38-44*). For information on refiner groundwood see Dorland et al. (*45*).

Kraft. The wood is readily reduced; strength is variable from slightly below to slightly above average, and the yield is normal (*20, 38, 41, 44, 47, 48*). The yield of bleached kraft pulps is increased by pretreatment with black liquor. For kraft pulp properties see Legg and Hart (*46*). Kraft pulps are very strong and useful for wrapping paper, high-grade printing paper, fiberboard, and hardboard. The pulp is often mixed with groundwood and other pulps for a wide range of products.

Magnefite. These pulps are superior to regular sulfite pulps (*49*).

Nitric acid. The "Nitrocell" process makes pulp about as strong as sulfite pulp and not so strong as kraft. Nitric acid pulp is produced in relatively high yield (*50*).

NSSC. Chemical consumption is high, and digestion time is relatively long (*47, 51, 52*).

Soda. See Wells, et al. (*53*). Cold soda pulping is not satisfactory (*54*).

Sulfite. Pulp can be produced by a 2-stage process; for pulp properties and methods, see Sanyer, et al. (*55*). Low-yield bleached sulfite pulp is used for fluffed pulp (*56*). Pitch is a problem with sulfite pulping. Satisfactory pulp is produced only from sapwood.

Other Information. For bleaching experiments see Andrews and DesRosiers (*57*).

Utilization of Wood and Bark

Use properties of wood. The wood is moderately light, moderately low in bending and compressive strength, lacks stiffness, is moderately soft, and is moderately low in shock resistance. It has moderately small shrinkage. It is average in workability with tools. It is not so good as white pine in holding nails and is more apt to split when nailed than red pine. It is moderately difficult to penetrate with preservative. In paint-holding ability it rates below white pine. The lumber is generally knotty and is somewhat prone to warp and check in drying.

Calorific value of wood.
millions of Btu/air-dry cord: 21.6
millions of kcal/air-dry cord: 5.4
Btu/lb (bone dry) 8930
kcal/kg (bone dry) 4962

Calorific value of bark.
Btu/ft^3 240,461
kcal/m^3 1714
Btu/oven-dry lb. 9393
kcal/kb 5219

Other uses of wood. The wood is used principally for pulpwood. Lumber is used for rough local construction and for boxes, crates, and shipping containers. Other uses are for ties, poles, posts, piles, and fuel.

Literature Cited

1. USDA, Forest Service, Agriculture Handbook No. 271, 1965, 762 p.

2. USDA, Forest Service. Agriculture Handbook No. 445, 1973, 114 p.

3. Crist, J. B., Dawson, D. H. and Nelson, J. A. Proc. 1977 TAPPI Forest Biology Wood Chemistry Conf., June 20-22, 1977, Madison, WI, pp. 211-216.

4. Kribs, D. A. Minn. Agr. Exp. Sta., Bull. 54, 1928, 14 p.

5. Marden, R. M., Lothner, D. C. and Kallio, E. USDA, Forest Serv. Res. Pap. NC-114, 1975, 9 p.

6. Hale, J. D. Pulp Paper Mag. Can. 56(13): 113-17 (1955).

7. Chang, Y. P. TAPPI Monograph Series No. 14, 1954, 249 p.

8. Grigal, D. F. and Sucoff, E. I. Tappi 49(11): 497-8(1966).

9. Erickson, J. R. USDA, Forest Service Res. Note NC-141, 1972, 3 p.

10. King, J. P. USDA, Forest Serv. Res. Pap. NC-23, 1968, pp. 5-9.

11. Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-202, 1973, 40 p.

12. Pronin, D. USDA, Forest Serv. Res. Pap. FPL-161, 1971, 16 p.

13. Wilde, S. A. and Voigt, G. K. Jour. Forestry 46(7): 521-3(1948).

14. USDA, Forest Service. Forest Prod. Laboratory. Agriculture Handbook No. 72, 1974.

15. Lamb, F. M. and Marden, R. M. Forest Prod. Jour. 18(9):76-82(1968).

16. Forest Products Laboratory. Unpublished data.

17. Clermont, L. P. and Schwartz, H. Pulp Paper Mag. Can. 52(13):103-5 (Dec., 1951).

18. Barnes, F. Chem. Met. Eng. 28:503(1923).

19. Mingle, J. G. and Boubel, R. W. Wood Sci. 1(1): 29-36 (July, 1968).

20. Chidester, G. H., Bray, M. W. and Curran, C. E. Tech. Assoc. Papers 23:661(1940); Paper Trade J. 109(13):36 (Sept. 28, 1939).

21. Chidester, G. H. and McGovern, J. N. Tech. Assoc. Papers 23:322(1940); Paper Trade J. 110 (10):39 (March 7, 1940).

22. Hajny, G. J. and Ritter, G. J. Tech. Assoc. Papers 25:595(1942); Paper Trade J. 113(13):83 (Sept. 24, 1941).

23. Swan, E. P. Can. Dept. Forestry, Inform. Rept. VP-X-115; 24 p. (Aug., 1973).

24. Sinclair, G. D. and Dymond, D. K. Pulp Paper Mag. Can. 72(7):78-81(T240-3) (July, 1971).

25. Sinclair, G. D. and Dymond, D. K. Can. J. Forest Res. 3(4):516-21(Dec., 1973).

26. Chapman, R. A., Nugent, H. M., Bolker, H. I., Manchester, D. F., Lumsden, R. H. and Redmond, W. A. CPPA Trans. Tech. Sect. 1(4):113-122 (Dec., 1975).

27. Hibbert, H. and Phillips, J. B. Can. J. Res. 4:1(1931).

28. Drew, J. and Pylant, G. D., Jr. Tappi 49(10): 430-8 (Oct., 1966).

29. Erdtman, H. Svensk Papperstidn. 46:226(1943).

30. Erdtman, H. Svensk Kem. Tid. 56:95(1944).

31. Institute of Paper Chemistry. Unpublished data.

32. Chang, Y.-P. and Mitchell, R. L. Tappi 38(5): 315-20 (May, 1955).

33. Milliken, D. E. Pulp Paper Mag. Can. 56(13): 106-8 (1955).

34. Detcher, T. E. and Jones, R. M. Paper Ind. 33(12): 1438-42 (Mar., 1952).

35. Stevens, R. J. Pulp Paper Mag. Can. 59(1): 96-101 (Jan., 1958).

36. Eberhardt, L. Paper Trade J. 140(8):30-2 (Feb. 20, 1956).

37. Wayman, M., Anderson, C. B. and Rapson, W. H. Pulp Paper Mag. Can. 69(9):51-60(T 225-34) (May 3, 1968).

38. McGovern, J. N., Schafer, E. R. and Martin, J. S. TAPPI Monograph No. 4:130(1947).

39. Paterson, H. A. Pulp Paper Mag. Canada 38:146 (1937).

40. Ritchie, F. I. Pulp Paper Mag. Can. 18:1110 (1920).

41. Running, K. D. Pulp Paper Mag. Can. 41(2):181 (1940).

42. Thickens, J. H. Experiments with jack pine and hemlock for mechanical pulp. U.S. Dept. Agr., Forest Service Bull. 1912. 29 p.

43. Thickens, J. H. and McNaughton, G. C. U.S. Dept. Agr., Bull. 343. 1916.

44. Wells, S. D. and Rue, J. D. U.S. Dept. Agr., Dept. Bull. 1485. May, 1927. 101 p.

45. Dorland, R. M., Holder, D. A., Leask, R. A. and McKinney, J. W. Pulp Paper Mag. Can. 63(2): T43-52 (Feb., 1962).

46. Legg, G. W. and Hart, J. S. Pulp Paper Mag. Can. 61(5): T299-304(May, 1960).

47. McGovern, J. N., Mackin, G. E. and Chidester, G. H. Tappi 32:179(1949).

48. Wells, S. D. Paper Ind. 5:786(1923).

49. Tomlinson, G. H., Tomlinson, G. H., II, Bryce, J. R. and Tuck, N. G. M. Pulp Paper Mag. Can. 59(C): 247-252(Conv., 1958).

50. Walter, H. K. TAPPI/CPPA Intern. Sulfite Pulping Recovery Conf. (Boston), Oct.-Nov., 1972: 181-96.

51. Chidester, G. H. Proc. Forest Products Research Soc. 3:197 (1949).

52. McGovern, J. N. and Keller, E. L. Pulp Paper Mag. Can. 49(9):93(1948).

53. Wells, S. D., Grabow, R. H., Staidl, J. A. and Bray, M. W. Tech. Assoc. Papers 6:43(1923); Paper Trade J. 76(2)4:49(June 14, 1923).

54. Brown, K. J. and McGovern, J. N. Paper Ind. 35(1):66-69 (April, 1953).

55. Sanyer, N., Keller, E. L. and Chidester, G. H. Tappi 45(2):90-104(Feb., 1962).

56. Aberson, G. M. TAPPI STAP No. 8:282-305; discn: 305-7 (May, 1969); publ. 1970).

57. Andrews, D. H. and DesRosiers, P. Pulp Paper Mag. Can. 67(C):T119-28 (Convention issue, 1966).

LOBLOLLY PINE

Scientific Name *Pinus taeda* L.

Synonyms Oldfield pine, North Carolina pine, shortleaf pine, yellow pine, southern pine, Arkansas pine.

Family Name Pinaceae.

Range Atlantic and Gulf Coastal plains. Sea level to about 800 ft (245 m) above sea level. The loblolly-shortleaf pine type occupies about 58 million acres (23.5 million ha) (*1*).

Silvics The tree is medium sized to large with a long, cylindrical bole, an open crown, and an extensive lateral root system. It grows on a wide variety of soils, from the flat, poorly-drained ones of the Coastal Plain to the old, residual ones of the Upper Piedmont. It grows best in soils with poor surface drainage, a deep surface layer, and a firm subsoil. In the Coastal Plain pure stands are found on river bottoms, and pure stands also occur on drier upland soils. On cutover lands this species has spread remarkably and is especially aggressive in forming pure stands on old fields. Throughout its range various mixtures are found with the other southern pines. Mixtures with various hardwoods are common and include sweetgum, various oaks, hickories and tupelos. Loblolly pine grows more rapidly over long periods of time than do the other species of southern pine. Large amounts of seeds are produced after about the twenty-fifth year. The species is rated as intolerant.

Tree Dimensions 90 to 110 ft (27 to 40 m) tall and 2 to 2.5 ft (61 to 76 cm) in diameter.

Pathology Resistance to decay: intermediate.

Although loblolly pine beyond the sapling stage are seldom killed by disease, fungi cause appreciable cull in older stands (*2*). The most important of these fungi is *Phellinus pini,* which causes heart rot, and *Phaeolus schweinitzii,* which causes butt rot. Young loblolly pine are susceptible to the root rot fungus, *Heterobasidion annosum,* and southern fusiform rust (*Cronartium fusiforme*).

The several species of Ips bark beetles cause the loss of over 100 million board feet (350,000 cubic m) of pine each year (*3*). The southern pine beetle (*Dendroctonus frontalis*) is the most destructive of the eastern species of bark beetles, with death to the tree resulting from girdling or the effects of a fungus, introduced by the beetles. Two additional pests of loblolly pine are the black turpentine beetle (*Dendroctonus terebrans*) and the loblolly pine sawfly (*Neodiprion taedae taedae*).

Gross Features of the Wood The wood cannot be separated with certainty from that of other southern yellow pines. The sapwood is nearly white to yellowish orange-white or pale yellow, and the heartwood ranges through shades of yellow and orange to reddish brown or light brown. The wood is moderately hard to hard and moderately heavy to very heavy, medium textured, with a distinct resinous, noncharacteristic odor, and without a characteristic taste. The transition from earlywood to latewood is very abrupt, but the widths of each vary within wide limits. A distinct growth ring figure is present. Rays are very fine and are not visible to the unaided eye except where they include a horizontal resin canal, forming a fine, close, inconspicuous fleck on the radial surface. Both longitudinal and horizontal resin canals are present. The longitudinal ones appear as whitish or brownish flecks which are conspicuous or relatively conspicuous with the naked eye, plainly distinct with a hand lens, numerous, confined largely to the central and outer portions of the ring, solitary or rarely 2 to 3 contiguous in a tangential line, generally visible as relatively inconspicuous streaks along the grain. Horizontal rays are less conspicuous and appear as whitish, relatively inconspicuous wood rays spaced at irregular intervals on the transverse surface. Longitudinal parenchyma cells are absent except immediately surrounding epithelial cells.

Microscopic Structure of the Wood

Tracheids. Average, 3.6 mm (1.2 to 5.9 mm) in length 35 to 45 μm in diameter and very thick fiber walls. Weight factor (unbleached kraft) 1.45 coarseness of 23.5 mg/100 m. Bordered pits in one row or paired on the radial walls; tangential pitting on the last few rows of latewood and first-formed earlywood tracheids; pits leading to ray parenchyma variable in size and shape (pinoid), 1 to 6 (generally 2 to 5) per crossfield; ray tracheid pits small and uniform in size, marginal and interspersed. Volume occupied, ca. 91%.

Resin Canals. Longitudinal, average, 90 to 150 μm in diameter; horizontal, less than 70 μm; thin-walled epithelial cells; tylosoids common in the heartwood. Volume occupied, <1%.

Rays. Two types, uniseriate and fusiform. The uniseriate rays are numerous and 1 to 8+ cells high. The fusiform rays are scattered, with a horizontal resin canal, 2- and 4-seriate in the central portion, tapering to uniseriate margins, up to 12+ cells high. Ray tracheids occur in both types of rays and are marginal and interspersed, with prominently dentate inner walls; marginal and interspersed tracheids are often 'n several rows; low rays frequently consist entirely of ray tracheids; ray parenchyma are thin walled. Volume occupied, ca. 8%.

Longitudinal Parenchyma. Absent.

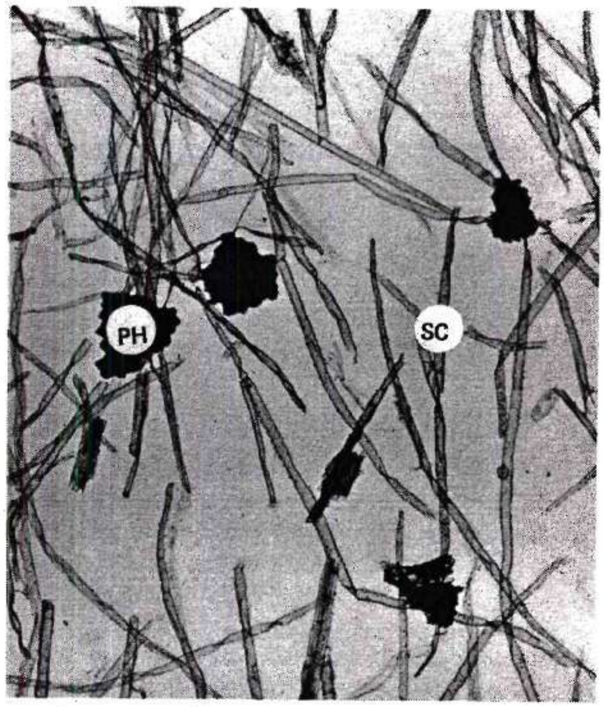
Publications in this area include Cote and Day (*4*), Howard and Manwiller (*5*), and Britt (*6*).

Gross Features of the Bark The structure of the rough, thick bark among closely related species of southern pines is quite similar, although external appearance between individual trees of one species is highly variable. In mature southern pine, the thick, large-scaled rhytidome generally consists of dark porous tissue subdivided by merging bands of periderms with thin and thick-walled cells. The innermost periderm separates the rhytidome from the inner bark. The much expanded, deformed and loosely arranged secondary phloem tissues in the rhytidome are in great contrast to the phloem in the inner bark. Southern pine barks generally fall in the low to intermediate bark density range. Bark of loblolly pine is quite variable. Scaly and nearly black in the young trees, it later appears as irregular dark-brownish scaly blocks changing to reddish-brown scaly plates in very old trees. The periderm bands are quite inconspicuous and slate gray. Measuring 0.85 to 2.0 in. (2.1 to 4.1 cm), the comparatively thick loblolly pine bark accounts for approximately 10% of the total log volume.

Microscopic Structure of the Bark

Bark characteristics of all southern hard pines generally overlap.

Young Trees or Branches. Protection for the young stem is provided by an epidermis consisting of one or more layers of epidermal cells which have a very thick and cutin-free surface. Beneath the epidermis in 2- to 3-year-old twigs are 2-3 layers of rectangular cells with thickened walls on the outer tangential surface and showing distinct lamellate layers and simple pits on the secondary walls. In very young bark, the periderm is composed of mainly thin-walled cells; it quickly develops alternate layers of thin- and thick-walled cells. The cortex consists of regular cortex cells, resin cells, and vertical resin canals. Parenchyma, sieve cells, and narrow phloem rays form the inner bark (secondary phloem).



Bark elements found on a 60-mesh screen when loblolly pine bark was pulped and screened. The proportions of elements obtained were about 90-95% sieve cells (SC) and a minor amount of phellem cells (PH). Magnification, 30X

Mature Trees

Outer Bark. Composed of dead cells, the outer bark has alternating layers of distorted phloem cells and periderm bands. Cut off and isolated by the successive periderm formations, these deformed phloem cells are crushed sieve cells and greatly expanded longitudinal parenchyma cells of the secondary phloem. Sieve cells greatly outnumber parenchyma cells in the inner bark, but in this old, isolated phloem tissue, the enormously enlarged parenchyma occupy most of the volume, accounting for the porous structure of the outer bark.

Periderms. The periderms, throughout most of their extent, lie in the tangential plane, generally parallel to one another, with the edges curving outward to merge with other periderm layers. Of the 3 bands within each periderm layer, the outer phellem is composed of thin-walled cork cells and thick-walled "stone" cells (sclerified cork cells). Compactly arranged, the suberized cork cells have unpitted cellulose walls and are approximately the same shape as the phellogen cells. Some of the sclerified phellem cells develop distinct lamellate layers of secondary walls and simple pits and form the only heavily lignified tissue. Although these thick-walled phellem cells occupy 10% or less of the rhytidome samples, they greatly influence density and hardness. Arranged in tangential bands of varying widths, the lignified phellem cells have distinct, irregular projections which interlock in coglike fashion with adjacent cells. In the midst of the periderm, the phellogen layer consists of a row of thin-walled meristematic cells which divide tangentially to produce the phellem to the outside and the phelloderm to the inside. Regularly aligned in usually 3-5 layers, phelloderm cells are compact close to the phellogen and loosely arranged and expanded with thinner walls closer to the secondary phloem region. Peridermal cells are rectangular in cross and radial section, and hexagonal, about 50 μm in height, tangentially.

Inner Bark. Relatively narrow, the inner bark is composed of thin-walled sieve cells, albuminous cells, longitudinal and ray parenchyma, and epithelial cells.

Sieve Cells. Comparable to xylem tracheids in size, shape and arrangement, sieve cells are the only distinctly elongated elements and the most abundant by volume. Radially aligned, these long slender cells have thin, non-lignified cellulosic walls with numerous sieve areas corresponding to tracheid pitting.

Parenchyma. Dispersed among the sieve cells, thin-walled longitudinal parenchyma occur in vertical strands. Abundant crystals composed of calcium oxalate are found in the lumina of both sieve cells and the longitudinal parenchyma.

Sclerenchyma. Absent in the inner bark.

Rays. Continuous with xylem rays, the radial alignment of the mostly uniseriate phloem rays becomes distorted a short distance from the cambium. Composed of albuminous cells, ray parenchyma and epithelial cells, all ray cells in the secondary phloem have thin, primary, unlignified walls. Ray tracheids are absent. Instead, erect structures called albuminous cells form the margins of most rays and are associated physiologically with sieve cells, dying and collapsing simultaneously with them. The horizontal resin canals of the fusiform rays are lined with epithelial cells which sometimes clog the ducts with tylosoids in older phloem.

Publications on bark structure include Howard (*7*), Martin (*8*) and Martin and Crist (*9*).

Physical Properties of Wood

Specific gravity	Green volume	0.47
	Air-dry volume	0.51
	Oven-dry volume	0.54
Density, lb/cu ft (kg/cu m)	Green	53 (849)
	Air-dry	36 (577)
	Oven-dry	34 (545)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	29 (464)

Specific gravity of loblolly pine averaged higher in the gulf coastal and Atlantic coastal regions than in areas inland. Specific gravity values increased from north to south, particularly in the western part of the range and along the Atlantic coast, but not in the Piedmont Region of North Carolina (*10*).

Overall decrease in specific gravity with increase in height of tree (*11*).

Specific gravity increased more than twofold from the beginning to the end of the ring (*12*).

According to Posey (*13*), the average tree responded to N fertilization with an increase in growth, decrease in wood specific gravity, decrease in radial double-wall thickness, and decrease in tracheid length.

In a comparison of the wood of thinned *vs.* unthinned loblolly pine, a threefold increase in radial growth was found to be accompanied by a significant increase in specific gravity and percentage of latewood in response to heavy thinning and pruning (*14*).

Branchwood specific gravity (green vol., o.d. wt.) averaged 0.449 for small, medium and large branches (*15*).

Other publications in this area include Cole, et al. (*16*), Einspahr, et al. (*17*), Fogg, et al. (*18*), Gilmore (*19*), Gilmore, et al. (*20*), McMillin (*21, 22*), Wahlgren and

Schumann (*23*), Wheeler, et al. (*24*), and Zobel, et al. (*25*).

Percent shrinkage, dried to 0% moisture content: r - 4.8, t - 7.4, v - 12.3 (*26*).

Percent moisture content, when green

Green basis	45
Oven-dry basis	81

Percent moisture content, oven-dry basis (*26*)

Heartwood	33
Sapwood	110

An additional publication on moisture content is Cole, et al. (*16*).

Physical Properties of Bark

Specific gravity, green volume	Inner bark	0.29
	Outer bark	0.34
	Total bark	0.33
Density , (100% moisture content)	Green weight/ green volume	0.57

Branchbark specific gravity (green vol., oven-dry wt.) averaged 0.314 for small, medium and large branches (*15*).

Specific gravity, oven-dry weight & volume (*27*)	0.56

Physical characteristics of the bark of loblolly pine are covered in a publication by Phillips and Schroeder (*28*).

Chemical Composition of Wood

Proximate Analyses.

	F.P.L.	Chidester et al. (*29*)	Wise (*30*) Sapwood	Wise and Ratliff (*31*)
Lignin, %	28.3	28.1	27.7	29.5
C.&B. cellulose, %	58.7	59.3	—	—
Alpha-cellulose, %	45.7	43.3	54.1*	46.6**
Hemicellulose, %	—	—	—	15.3
Hemicellulose A, %	—	—	12.2	—
Hemicellulose B, %	—	—	3.3	—
Ash, %	—	—	—	0.28
Pentosans				
Total, %	12.4	12.6	—	—
In cellulose, %	—	9.3	—	—
Mannan, %	5.1	—	—	4.7
Acetyl, %	—	—	—	1.1
Xylan (cor. for uronic anhydride), %	—	—	—	3.8
CH_2 (from MeO not in lignin), %	—	—	—	0.20
Solubility in				
Alcohol-benzene, %	2.7	3.8	5.4	—
Ether	1.9	2.5	—	—
1% NaOH	9.9	13.4	—	—
Hot Water	1.8	3.1	1.4	—
Uronic anhydride	—	—	—	3.8

*chlorite method
**cor.

Koch (*32*) found the ash content to be 0.4%.

Extractives. Alcohol-benzene extractives, 5.4%; water extractives (after alcohol-benzene), 1.4% (*33*).

Successive extractions: ether, 2.7%; alcohol, 1.14%; water, 0.56%; total, 4.4% (*34*).

Benzene extractives averaged 2.98% on 68 samples of sapwood over a 10-month period (*35*).

Composition of ether extractives from green wood (based on oil): unsaponifiable material, 15.80%; rosin acids, 37.2%; saturated fatty acids, 2.28%; and unsaturated fatty acids, 41.32% (*36*).

Tannin was not found (*37*).

Small amounts of pectic substances have been isolated (*38*).

For monoterpenes see Rockwood (*45*).

For general information on extractives see Pearl (*39*) and Zinkel (*40*).

Wahlenberg (*41*) has analyzed the extractives in spring wood and summer wood, in both sapwood and heartwood.

For additional information see Drew and Pylant (*42*), Buchanan, et al. (*43*), and Lindstedt and Misiorny (*44*).

Other Information. For elemental analysis see Metz and Wells (*46*).

Chemical Composition of Bark

Proximate Analyses.

	McGinnis and Parikh (*47*)	Institute Paper Chemistry, Project 3212, Report 5	Pearl (*48*)
Klason lignin, %	46.0		
Holocellulose, %	41.7		
Ash, %	–	0.8	
Soluble in			
Alcohol-benzene, %	–	8.5	–
Petroleum ether	3.1	–	1.48- 4.52
Water	–	–	7.05-13.34
Ether	–	–	0.79- 2.43
Ethanol	4.8	–	0.38- 1.71
Ethyl acetate	–	–	1.06- 3.59
Benzene	1.2	–	–
Cold water	3.0	–	–
Hot water	7.8	–	–

Carbohydrates. For carbohydrates see McGinnis and Parikh (*47*).

Extractives. For information on extractives see Pearl (*39*).

Other Information. For elemental composition see White et al. (*49*) and Harder & Einspahr (*50*).

Pulping

Alkali. For high concentration alkali pulping see Connors and Sanyer (*51*).

Alkaline sulfite. A process that combines sulfide or hydrosulfide with carbonate and sulfite gives yields of southern pines 6-10% higher than does kraft pulping (*52*).

Asplund. The pulp is used for roofing felts.

Groundwood. The pulp is used for fiberboard.

Kraft. The wood is reduced readily and the pulp is strong and yield is normal; it is used for high-grade wrapping and bag papers and fiberboard (Bray and Curran, *53-60*) and linerboard.

For kraft pulp chlorination see Ackert (*61*) and Ackert, et al. (*62*).

For wood characteristics and kraft pulp and paper properties see Foelkel (*63*), and Barefoot, et al. (*64*).

Kraft pulping to a permanganate number of 16-18 and 25-30 gave very strong pulps and low yields.

Kraft and prehydrolysis kraft pulping and bleaching by chlorination plus cold extraction with strong kraft white liquor or bleaching with sodium hydroxide and calcium hypochlorite produced nitrating-grade pulps and waterleaf sheets; properties are given (*65*).

Magnesium bisulfite. Equal amounts of slash and loblolly pine were readily pulped despite the phenolic extractives of the heartwood. Pitch problems were avoided by long-term storage which, however, resulted in blue stain; even so, the unbleached pulp was brighter than kraft pulp (*66*).

Mechanical. The wood is reduced moderately well and color is fair. It requires 50% more power than white spruce and must be relatively free of heartwood for light-colored, unbleached pulp. It is used for book papers, newsprint, wallboard, and insulating board (*67-72*) and paper board.

NSSC. The pulp is used for corrugating medium.

Oxygen. Oxygen pulping with sodium borate or NaOH gives a yield higher than in kraft pulping; the addition of KI improves strength (*73*). For information on oxygen pulping see Landucci, et al. (*74*).

Polysulfide. This process can be used.

Sulfite. The wood is reduced fairly readily, strength is fair, yield is normal, and color is a decided reddish-gray. It is suitable for rayon pulp. Bleach consumption is reasonable. Heartwood is difficult to pulp (*75-82*).

Thermochemical. For information see Sinkey (*83*).

Utilization of Wood and Bark

Use properties of wood. It is used for building construction of all kinds, railway ties, poles, cooperage, veneer, and piling; it is also used for excelsior, fuelwood, posts, and mine timbers. Nail-holding ability is intermediate. Heartwood is intermediate in durability. The sapwood is not durable and can be treated with preservatives. The wood has moderately large shrinkage. Seasoned wood stays in place well.

Considerable quantities of southern pines are used in making wrapping paper and shipping container board almost entirely by the sulfate process. The resin doesn't interfere as it does with sulfite or groundwood pulping. For sulfite and groundwood, sapwood only can be used (i.e., young trees 25-30 yr). Some sulfite pulp is used for viscose rayon. High-quality white paper is made from southern pine bleached sulfite pulp.

Calorific value of wood.

Stemwood has
8600 Btu/ovendry lb
(4780 kcal/kg)
7855 Btu/air-dry lb
(4381 kcal/kg)

Calorific value of bark.

9320 Btu/oven-dry lb
5178 kcal/kg

Other uses of wood. It is used for building material such as interior finish, ceiling, frames and sash, wainscoting, weatherboarding, sheathing, subflooring and joists, and for boxes and crates, agricultural implements, motor vehicles, low-grade furniture, caskets and burial boxes, woodenware, and novelties; slack cooperage; used for heavier construction when treated with preservative to increase decay or insect resistance.

Literature Cited

1. USDA, Forest Service. USDA, For. Resource Rept. No. 17, 1965, 235 p.

2. USDA, Forest Service. Agriculture Handbook No. 271, 1965, 762 p.

3. USDA, Forest Service. Forest Pest Leaflet No. 129, 1971, 7 p.

4. Cote, W. A. and Day, A. C. State Univ. Coll. of Forestry at Syracuse Univ. Tech. Publ. No. 95, 1969, 70 p.

5. Howard, E. T. and Manwiller, F. G. Wood Sci. 2(2):77-86(1969).

6. Britt, K. W. Tappi 48(1):7-11(1965).

7. Howard, E. T. Wood Sci. 3(3):134-48(1971).

8. Martin, R. E. Forest Prod. Jour. 19(8): 23-30 (1969).

9. Martin, R. E. and Crist, J. B. Wood & Fiber 2(3): 269-79 (1970).

10. Saucier, J. R. and Taras, M. A. USDA, Forest Serv. Res. Pap. No. SE-45, 1969, 16 p.

11. Okkonen, E. A., Wahlgren, H. E. and Maeglin, R. R. Forest Prod. Jour. 22(7):37-42(1972).

12. Ifju, G. and Labosky, P., Jr. Tappi 55(4):524-9 (1972).

13. Posey, C. E. Ph.D. Thesis, N. C. State of Univ. of N. C. at Raleigh, 1964, 106 p.

14. Smith, D. M. USDA, Forest Serv. Res. Pap. No. FPL-89, 1968, 12 p.

15. Phillips, D. R., Clark, A., III and Taras, M. A. Wood Sci. 8(3):164-9 (1976).

16. Cole, D. E., Zobel, B. J. and Roberds, J. H. Tappi 49(4):161-6(1966).

17. Einspahr, D. W., Peckham, J. R. and Mathes, M. C. Forest Sci. 10(2): 165-73(1964).

18. Fogg, P. J., Choong, E. T., Chang, B. Y. and Yang, C. H. Abstr., 26th Annual Mtg. Forest Prod. Res. Soc., Madison, WI, p. 6-7, 1972.

19. Gilmore, A. R. Jour. Forestry 65(9):631(1967).

20. Gilmore, A. R., Boyce, S. G. and Ryker, R. A. Forest Sci. 12(4): 399-405(1966).

21. McMillan, C. W. Wood Sci. Tech. 2(3): 166-176 (1968).

22. McMillan, C. W. Wood Sci. 2(1):26-30(1969).

23. Wahlgren, H. E. and Schumann, D. R. USDA, Forest Serv. Res. Pap. No. FPL-176(1975).

24. Wheeler, E. Y., Zobel, B. J. and Weeks, D. L. Tappi 49(11):484-90(1966).

25. Zobel, B. J., Kellison, R. C., Matthias, M. F. and Hatcher, A. V. N. C. Agric. Expt. Sta. Tech. Bull. No. 208, 1972, 56 p.

26. USDA, Forest Service. Forest Prod. Laboratory. Agriculture Handbook Nno. 72, 1974.

27. Harkin, J. M. and Rowe, J. W. USDA, Forest Serv. Res. Note No. FPL-091, 1969, 42 p.

28. Phillips, D. R. and Schroeder, J. G. Forest Prod. Jour. 22(10):30-3(1972).

29. Chidester, G. H., McGovern, J. N. and McNaughton, G. C. Tech. Assoc. Papers 21:264(1938): Paper Trade J. 107(4):36(July 28, 1938).

30. Wise, L. E. Private communication.

31. Wise, L. E. and Ratliff, E. K. Anal. Chem. 19:459 (1947).

32. Koch, P. Utilization of the southern pines. Vol. K. The raw material. USDA., Forest Serv. Agriculture Handbook No. 420, 1972. 734 p.

33. Institute of Paper Chemistry. Unpublished data.

34. Lewis, H. F. Tappi 33:299(1950).

35. Bishop, G. N. and Marckworth, G. D. J. Forestry 31:953(1933).

36. Max, K. Southern Pulp Paper J. 7(8):36(1945).

37. Russell, A. J. Am. Leather Chemists Assoc. 39:173 (1944).

38. Anderson, E. J. Biol. Chem. 165:233(1946).

39. Pearl, I. A. Tappi 58(7):142-145(July, 1975).

40. Zinkel, D. F. Tappi 58(2):118-121(Feb., 1975).

41. Wahlenberg, E. G. Loblolly pine. Duke Univ., Durham, North Carolina. 1960.

42. Drew, J. and Pylant, G. D., Jr. Tappi 49(10): 430-8(Oct., 1966).

43. Buchanan, M. A., Sinnett, R. V. and Jappe, J. A. Tappi 42:578-83(1959).

44. Lindstedt, G. and Misiorny, A. Acta Chem. Scand. 5:131-8(1951).

45. Rockwood, D. L. North Carolina State Univ. Ph.D. Thesis, 1972: 134 p.

46. Metz, L. J. and Wells, C. G. USDA Forest Service Res. Pap. SE-17, 20 pp. Southeast Forest Exp. Sta., Asheville, N. C.

47. McGinnis, G. D. and Parikh, S. Wood Sci. 7(4):295-297 (April, 1975).

48. Pearl, I. A. Tappi 58(10):146-149(Oct., 1975).

49. White, J. D., Wells, C. G.,and Clark, E. W. Can. J. Bot. 48(6):1079-1084 (June, 1970).

50. Harder, M. L. and Einspahr, D. W. To be submitted to Tappi.

51. Connors, W. J. and Sanyer, N. Tappi 58(2)(Feb., 1975).

52. Shick, P. E. Tappi 53(8):1451-1457(Aug., 1970).

53. Bray, M. W. and Curran, C. E. Tech. Assoc. Papers 21:458(1938); Paper Trade J. 105(20):39(Nov. 11, 1937).

54. Bray, M. W., Martin, J. S. and Schwartz, S. L. Southern Pulp Paper J. 2(6):35(1939).

55. Curran, C. E. and Bray, M. W. Tech. Assoc. Papers 14:359(1931); Paper Trade J. 92(1):47(Jan. 1, 1931).

56. Holzer, W. F. and Booth, K. G. Tappi 33:95 (1950).

57. Martin, J. S. Southern Pulp Paper J. 6(7):13 (1943).

58. Rasch, R. H. Paper Ind. 17:948(1936).

59. Wells, S. D. Paper 27(12):16(Nov. 24, 1920).

60. Wells, S. D. and Rue, J. D. U.S. Dept. Agr., Dept. Bull. 1485. May, 1927. 101 p.

61. Ackert, J. E. Univ. Idaho Ph.D. Thesis, 1973; 267 p.

62. Ackert, J. E., Koch, D. D. and Edwards, L. L. Tappi 58(10):141-145 (Oct., 1975).

63. Foelkel, C. E. B. Papel 37:49-67(Jan., 1976).

64. Barefoot, A. C., Hitchings, R. G., Wilson, E. H. and Kellison, R. C. Proc. Symp. Growth Acceleration Effect on Wood Props. (U.S. Forest Prods. Lab.) K 1-33; discn. K34-7(Nov., 1971; publ., 1972).

65. Simmonds, F. A. and Chidester, G. H. Sulfate and prehydrolysis-sulfate pulps for nitration. Relation of pulp characteristics to certain preparation variables. Madison, Wis., U.S. Forest Prods. Lab. [Rept. No. 2189], June, 1960. 41 p.

66. Keller, E. L. and Fahey, D. J. Tappi 51(2): 98-103(Feb., 1968).

67. Fuller, A. C. and Carpenter, C. Tech. Assoc. Papers 21:438(1938); Paper Trade J. 107(9):30(Sept. 1, 1938).

68. Schafer, E. R., Pew, J. C. and Knechtges, R. G. Tech. Assoc. Papers 19:279(1936); Paper Trade J. 103(2):29(July 9, 1936).

69. Thickens, J. H. and McNaughton, G. D. U.S. Dept. Agr., Bull. 343. 1916.

70. Walker, W. J. Tech. Assoc. Papers 20:379(1937); Paper Trade J. 105(12):44 (Sept. 16, 1937).

71. Wells, S. D. and Rue, J. D. U.S. Dept. Agr., Dept. Bull. 1485. May, 1927. 101 p.

72. Wynne-Roberts, R. I. Tech. Assoc. Papers 20:258 (1937); Paper Trade J. 104(6):46(Feb. 11, 1937).

73. Minor, J. L. and Sanyer, N. Tappi 57(5):120-2 (May, 1974).

74. Landucci, L. L., Minor, J. L. and Sanyer, N. Can. Wood Chem. Symp. (Chem. Inst. Can./CPPA. Chateau Frontenac), Extended Abstrs. Papers Presented 4:71-4 (July 4-6, 1973).

75. Chidester, G. H. and McGovern, J. N. Tech. Assoc. Papers 23:322(1940); Paper Trade J. 110(10):39(March 7, 1940).

76. Holzer, W. F. and Booth, K. G. Tappi 33:95 (1950).

77. McGovern, J. N. Paper Trade J. 103(20):29 (1936).

78. McGovern, N. N. and Chidester, G. H. Tech. Assoc. Papers 24:679(1942): Paper Trade J. 113(16):32(Oct. 16, 1941).

79. Pillow, M. Y., Chidester, G. H. and Bray, M. W. Southern Pulp Paper J. 4(7):6(1941).

80. Rasch, R. H. Paper Ind. 17:948(1936).

81. Rommel, G. M. Chem. Met. Eng. 40:197(1933).

82. Wells, S. D. and Rue, J. D. U.S. Dept. Agr., Dept. Bull. 1485. May, 1927. 101 p.

83. Sinkey, J. D. CPPA Ann. Mtg. (Montreal) Preprints 64A:21-28(Jan. 31-Feb. 3, 1978).

SLASH PINE

Scientific Name *Pinus elliottii* Engelm.

Synonyms Yellow slash pine, swamp pine, pitch pine

Family Name Pinaceae

Range Southeastern United States; usually at elevations less than 300 ft (91 m) above sea level. The slash-longleaf pine type occupies about 19 million acres (7.7 million ha) in the Southeast (*1*).

Silvics Slash pine has a long, cylindrical bole, a dense rounded crown, and a deep root system. In old stands this species occupies the moist depressions, whereas longleaf pine occupies the drier sites. With fire protection slash pine also invades drier hummocks. On cutover lands it is very aggressive and quickly takes over abandoned land which is at all moist. This tree is intermediate in tolerance but it is more tolerant than longleaf pine.

Tree Dimensions 80-90 ft (24-31 m) tall and 2 ft (61 cm) in diameter.

Pathology Resistance to decay: intermediate.

The most important decay-causing fungus in slash pine, as in loblolly pine, is red heart rot (*Phellinus pini*), particularly severe in mature trees. Another rot of slash pine is *Phaeolus schweinitzii*, a butt rot. Young slash pine are susceptible to the root rot, *Heterobasidion annosum*, and southern fusiform rust (*Cronartium fusiforme*).

The several species of Ips bark beetles cause the loss of over 100 million board ft (350,000 cu m) of pine each year (*2*) and are most damaging during dry spells. The black turpentine beetle (*Dendroctonus terebrans*) causes severe losses in turpentine orchards. Attacks are usually limited to the lower 6 ft of the trunks of standing trees. The red-headed pine sawfly (*Neodiprion lecontei*) is a problem in young plantations since it prefers trees less than 15 ft (4.6 m) in height.

Gross Features of the Wood Similar to loblolly pine. Earlywood zone is usually wide to very wide.

Microscopic Structure of the Wood See the description for loblolly pine.

Tracheids. Average length, 4.6 mm.

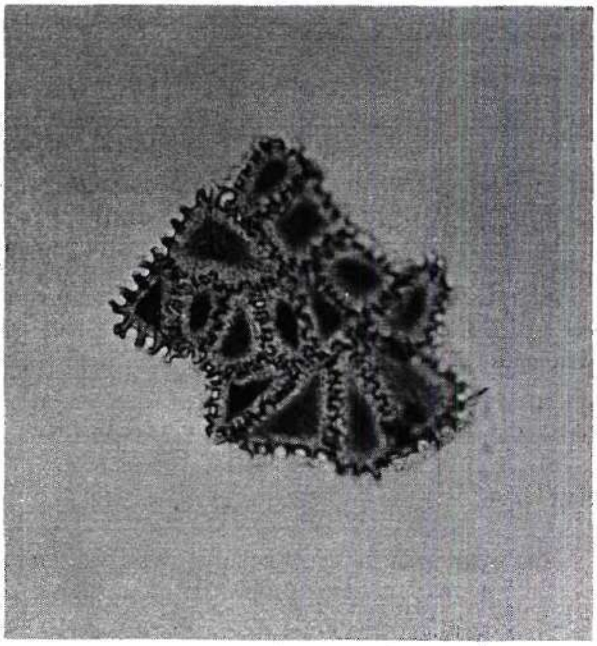
A publication relating to coarseness in slash pine is Britt (*3*). Other publications on wood ultrastructure and anatomical characteristics of stemwood include Cote and Day (*4*) and Howard and Manwiller (*5*).

Gross Features of the Bark Comprising approximately 16% of the log volume, the bark of the mature slash pine is about ¾-1½ in (2-4 cm) thick. Deeply furrowed, the large, flat plates of rhytidome expose reddish-brown-colored phloem tissues and pinkish-colored layers of periderm. The rather narrow inner bark, usually about 1/16-in wide (0.2 cm), is creamy yellow, turning brown after exposure. The outer bark can account for 85-95% of the total bark thickness by weight. A publication by Miller (*6*) describes variation in bark thickness by site, tree size and distance up the stem.

Microscopic Structure of the Bark

Young Trees or Branches. Similar in structure to the other southern pines, the young bark of the slash pine is composed of an epidermis, a suggested hypodermis, the periderm, cortex and secondary phloem of parenchyma, sieve cells, and narrow phloem rays. Chang (*7*) reports two minor variations in young slash pine. Thick-walled cells develop very early in the periderm, and sclereids — "lignified" cortex cells retaining their original size and shape — occur in the cortical region.

Mature Trees. Bark characteristics of all southern hard pines generally overlap.



Phellem cells isolated from slash pine bark. Magnification 185X.

Rhytidome. The narrow rhytidome layers are composed of deformed sieve cells and greatly expanded parenchyma and phloem ray cells from the secondary phloem isolated by rather broad periderm layers.

Periderm. Well-developed, the periderm consists of 3-5 layers of phelloderm, a layer of phellogen, and alternating thin and thick-walled phellem cells. Probably lignified phelloderm cells, these bands of thick-walled cells (stone cells) show distinct lamellate layers of secondary wall thickenings with simple pits (*7*).

Sieve Cells. According to Chang (*7*), sieve cells are usually about 25 μm in radial diameter and 40 μm in tangential diameter in cross section and vary in length from 2.4-4.6 mm with an average length of 3.48 mm. Oval to circular-shaped sieve areas, aligned in single vertical rows, are predominantly on the radial walls. Styloid crystals are in sieve cells close to the cambial area. Sieve cells comprise 54% of the tissue elements of the secondary phloem (*7*).

Sclerenchyma. Absent in the inner bark.

Parenchyma. Phloem parenchyma cells in the proximity of the cambium zone are similar in size and shape to the sieve cells in the same area. After a few seasons' growth, many parenchyma cells expand, squeezing the adjacent sieve cells out of shape and position, and become oval to circular in cross-section with diameters often up to 100 μm. The length of a parenchyma strand is usually about the same length as the adjacent sieve cells. Parenchyma comprise 38% of the tissue elements of the secondary phloem (*7*).

Rays. Radially bordering sieve and parenchyma cells are uniseriate and fusiform phloem rays. The uniseriate rays are usually approximately 10 cells and 300 μm in height. Horizontal resin canals are present in the fusiform rays. These canals are bordered with 3-4 thin-walled epithelial cells.

Publications on bark structure include Howard (*8*), Martin (*9*), and Martin and Crist (*10*).

Physical Properties of Wood

Specific gravity	Green volume	0.56
	Air-dry volume	0.61
	Oven-dry volume	0.66
Density, lb/cu ft (kg/cu m)	Green	58 (930)
	Air-dry	43 (689)
	Oven-dry	41 (567)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	35 (560)

Specific gravity increased from north to south and west to east (*11, 12*).

Overall decrease in specific gravity with increase in height of tree (*13*).

Specific gravity of 11-year-old trees was 0.42, topwood of mature trees was 0.41, and merchantable wood of mature trees was 0.48 (*14*).

Fertilization reduced the specific gravity of the wood and latewood percentage at the upper position in the stem and increased the amount of alcohol-benzene extractives at the lower position (*15*). In another study, fertilization did not reduce specific gravity but altered specific gravity trends within the stem (*16*).

Branchwood specific gravity (green volume, oven-dry weight) averaged 0.434 for small, medium, and large branches (*17*).

Other publications in this area include: Cole, et al. (*18*), Howard (*19*), Jurbergs (*20*), Sohn (*21*), van Buijtenen

(*22*), Wahlgren and Schumann (*23*), White and Saucier (*24*), and Zobel, et al. (*25*).

Percentage shrinkage, dried to 0% moisture content: r - 5.5, t - 7.8, v - 12.2.

Percent moisture content, when green

Green basis	40
Oven-dry basis	66

An additional publication on moisture content is Cole, et al. (*18*).

Physical Properties of Bark

Specific gravity, green volume	Inner bark	0.34
	Outer bark	0.36
	Total bark	0.35
Density (100% moisture content)	Green weight/ green volume	0.72

Branch bark specific gravity (green volume, oven-dry weight)averaged 0.402 for small, medium and large branches (*17*).

Physical characteristics of the bark of slash pine is covered in a publication by Phillips and Schroeder (*26*).

Chemical Composition of Wood

Proximate Analyses.

	F.P.L. (*27*)	Schwartz and Bray (*28*)	Chidester, et al. (*29*)	Wise (*30*)	Wise and Ratliff (*31*)
Lignin, %	28.0	24.9	27.3	27.1	26.05
Holocellulose, %	68.5	–	–	–	–
C.&B. cellulose, %	–	58.7	60.5	–	–
Alpha-cellulose, %	46.1	47.6	45.7	55.9[a]	49.7
Hemicellulose A, %	–	–	–	10.7	10.3[b]
Hemicellulose B, %	–	–	–	3.6	3.5[c]
Ash, %	0.2	–	–	–	0.25
Pentosans					
Total, %	8.6	9.1	12.3	–	–
In cellulose, %	6.6	7.5	8.5	–	–
Mannan, %	–	–	–	–	7.8
Acetyl, %	–	–	–	–	1.00
CH_2 (from MeO not in lignin), %	–	–	–	–	0.37
Solubility in					
Alcohol-benzene, %	2.6	6.4	2.7	2.8	2.75
Ether, %	2.0	5.1	1.4	–	–
1% NaOH, %	9.9	14.7	11.2	–	–
Hot water, %	2.5	3.9	1.9	0.8	–
Water (after alcohol-benzene), %	–	–	–	–	0.8
Xylan, %	–	–	–	–	8.25
Uronic anhydride, %	–	–	–	–	4.6

[a]chlorite method
[b]5% KOH
[c]24% KOH

Koch (*32*) found the ash content to be 0.7%.

Extractives. See Drew and Pylant (*33*), Max (*34*), Buchanan,et al. (*35*), and Pearl (*36*).

Alcohol-benzene extractives, 2.8%; water extractives (after alcohol-benzene) 0.8% (*37*).

The benzene extractives of sapwood averaged 3.03% for

72 samples over a 5-month period (*38*).

The distribution and composition of the ether extractives in young turpentined and unturpentined trees have been examined. No material difference between these types was noticed except in back of the face (*39*).

Tannins are absent (*40*).

The distribution of mannans in the various hemicellulose fractions of slash pine was studied; the fraction most readily extracted by alkali contained the lowest percentage of mannan, whereas the least soluble fraction showed the highest mannan content. Over half the mannose units, however, were retained in the resistant alpha-cellulose residue. The total mannan in the wood was 10.0% (*41*).

Chemical Composition of Bark

Proximate Analyses.

	Chang and Mitchell (*42*)	Institute Paper Chemistry, Project 3212, Report 5	Pearl (*43*)
Ash, %	0.6	0.8	–
Methoxyl, %	3.95	–	–
Solubility in			
Benzene, %	3.4	–	–
95% Alcohol, %	10.6	–	0.50- 1.22
Hot water, %	3.7	–	–
1% NaOH, %	28.9	–	–
Alcohol-benzene, %	–	8.4	–
Water, %	–	–	8.08-13.5
Ether, %	–	–	0.96- 1.22
Ethyl acetate, %	–	–	1.35- 3.46

Carbohydrates. For reducing sugars from extractive-free bark see Chang and Mitchell (*42*).

Extractives. For information on extractives see Drew and Pylant (*33*) and Pearl (*44*).

An alcohol-benzene extractives level of 8.4% for bark was found by The Institute of Paper Chemistry (Project 3212, Report 5).

Other information. Calcium content of 0.2% and silica content of 0.04% were found by The Institute of Paper Chemistry (Project 3212, report 5).

For information on elements in bark, see Harder and Einspahr (*45*).

Pulping

Groundwood. Only sapwood (trees 25-30 yr) can be used. The pulp is used for fiberboards.

Kraft. The wood is readily reduced, the pulp is strong, and the yield is normal (*47, 48*). Kraft pulping to permanganate numbers of 16-18 and 25-30 gave very strong pulps and low yields. Continuous pulping of shredded chips gave pulps of high yield and high quality (*49*).

For properties of kraft pulps see Wangaard, et al. (*50*), Wangaard, et al. (*51*), and Wangaard and Woodson (*52*).

The pulp is used for bag papers, paperboard (*46*), wrapping paper and shipping container board.

Magnesium bisulfite. Equal amounts of slash and loblolly pine were readily pulped despite the phenolic extractives of the heartwood. Pitch problems were avoided by long-term storage which, however, resulted in blue stain; even so, the unbleached pulp was brighter than kraft pulp (*53*).

Mechanical. Although the young, fast-growth wood is suitable, its pulps cause trouble in papermaking because their pitch content limits the proportion in which some of them can be used. For making light-colored unbleached pulp the wood must be relatively free of heartwood (*54, 55*). The pulp is used for newsprint and paperboard.

NSSC. Pulped bark causes some loss in strength for slash pine pulps (*56*).

Oxygen-alkali. Single-stage oxygen-alkali pulps were comparable in strength to semichemical pulps (*57*).

Sulfite. With slight modifications of the standard process, fair pulps with a reasonable bleach consumption can be made, provided young growth or material containing a comparatively small amount of heartwood is used; heartwood is difficult to pulp. Yield is normal (*58-60*). Chips pulped with sodium sulfite gave a higher yield than when pulped with sulfite-carbonate or kraft liquors; the strength was as good as from kraft pulping (*61*). Only sapwood (young trees 25-30 yr) can be used. The pulp is used for viscose rayon and high-quality white paper.

Utilization of Wood and Bark

Use properties of wood. The wood is hard, heavy, durable, stiff, strong, and tough. The less dense type holds nails well, does not split easily, and takes paint well. It is typically the heaviest and strongest of the southern pines with longleaf a close second.

Calorific Value of wood.

Btu/lb air dry	7885
kcal/kg air dry	4381

Calorific value of bark.

Btu/lb	9002
kcal/kg	5000

Chemical uses of wood. The wood is used for turpentine and rosin. It is alleged to excel longleaf pine in resin production with equal quality.

Other uses of wood. The wood is used for railway ties, telephone and telegraph poles, mine timbers, heavy construction, flooring, car construction, and ship and boat building.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 445, 1973, 114 p.

2. USDA, Forest Service. Forest Pest Leaflet No. 129, 1971, 7 p.

3. Britt, K. W. Tappi 48(1):7-11(1965).

4. Cote, W. A. and Day, A. C. State Univ. Coll. of Forestry at Syracuse Univ., Tech. Publ. No. 95, 1969, 70 p.

5. Howard, E. T. and Manwiller, F. G. Wood Sci. 2(2):77-86(1969).

6. Miller, S. R. Union Camp Corp. Woodland Res. Note No. 10, 1961, 3 p.

7. Chang, Y. P. New York, TAPPI Monograph Series No. 14, 1954, 249 p.

8. Howard, E. T. Wood Sci. 3(3):134-48(1971).

9. Martin, R. E. Forest Prod. Jour. 19(8):23-30 (1969).

10. Martin, R. E. and Crist, J. B. Wood & Fiber 2(3): 269-79(1970).

11. Goddard, R. E. and Strickland, R. K. Tappi 45(7): 606-8(1962).

12. Saucier, J. R. and Taras, M. A. USDA, Forest Serv. Res. Pap. SE-45, 1969, 16 p.

13. Okkonen, E. A., Wahlgren, H. E. and Maeglin, R. R. Forest Prod. Jour. 22(7):37-42(1972).

14. Zobel, B. J., Kellison, R. C. and Kirk, D. G. Proc. Symposium on the Effect of Growth Acceleration on the Properties of Wood, Madison, WI, Nov. 10-11, 1971.

15. Smith, D., Wahlgren, H. and Bengtson, G. W. Proc. Symposium on the Effect of Growth Acceleration on the Properties of Wood, Madison, WI, Nov. 10-11, 1971.

16. Gooding, J. W. M. S. Thesis, Auburn Univ., Auburn, Ala., 1970, 79 p.

17. Phillips, D. R., Clark, A., III and Taras, M. A. Wood Sci. 8(3):164-9(1976).

18. Cole, D. E., Zobel, B. J. and Roberds, J. H. Tappi 49(4):161-6(1966).

19. Howard, E. T. Wood Sci. 5(4):312-17(1973).

20. Jurbergs, K. A. Forest Sci. 9(2):181-7(1963).

21. Sohn, S. I. and Goddard, R. E. Proc. 22nd Northeastern Forest Tree Improv. Conf., Aug. 7-9, 1974, Syracuse, N.Y.

22. van Buijtenen, J. P. Tappi 47(7):401-4(1964).

23. Wahlgren, H. E. and Schumann, D. R. USDA, Forest Serv. Res. Pap. FPL-176, 1975.

24. White, J. F. and Saucier, J. R. Tappi 49(5): 230-2(1966).

25. Zobel, B. J., Kellison, R. C., Matthias, M. F. and Hatcher, A. V. NC Agricultural Expt. Sta. Tech. Bul. No. 208, 1972, 56 p.

26. Phillips, D. R. and Schroeder, J. G. Forest Prod. Jour. 22(10):30-3(1972).

27. Forest Products Laboratory. Unpublished data.

28. Schwartz, S. L. and Bray, M. W. Tech. Assoc. Papers 24:139(1941); Paper Trade J. 113(10):33 (Sept. 4, 1941).

29. Chidester, G. H., McGovern, M. N. and McNaughton, G. C. Tech. Assoc. Papers 21:264(1938); Paper Trade J. 107(4):36(July 28, 1938).

30. Wise, L. E. Private communication.

31. Wise, L. E. and Ratliff, E. K. Anal. Chem. 19:459(1947).

32. Koch, P. Utilization of the southern pines. Vol. I. The raw material. U.S.D.A., Forest Serv. Agriculture Handbook No. 420, 1972. 734 p.

33. Drew, J. and Pylant, G. D., Jr. Tappi 49(10): 430-8(Oct., 1966).

34. Max, K. W. Southern Pulp Paper Mfr. 7(9):22 (1945).

35. Buchanan, M. A., Sinnett, R. V. and Jappe, J. A. Tappi 42:578-83(1959).

36. Pearl, I. A. Tappi 58(7):142-5(July, 1975).

37. Institute of Paper Chemistry. Unpublished data.

38. Bishop, G. N. and Marckworth, G. D. J. Forestry 31:953(1933).

39. Kurth, E. F. and Sherrard, E. C. Ind. Eng. Chem. 23:1156(1931).

40. Russell, A. J. Am. Leather Chemists Assoc. 38:144(1943).

41. Wise, L. E. and Ratliff, E. K. Arch. Biochem. 19:292(1948).

42. Chang, Y.-P. and Mitchell, R. L. Tappi 38(5): 315-20(May, 1955).

43. Pearl, I. A. Tappi 58(10):146-9(Oct., 1975).

44. Pearl, I. A. Tappi 58(9):135-7(Sept., 1975).

45. Harder, M. L. and Einspahr, D. W. To be submitted to Tappi.

46. Bray, M. W. and Curran, C. E. Tech. Assoc. Papers 21:458(1938); Paper Trade J. 105(20):39(Nov. 11, 1937).

47. Schwartz, S. L. and Bray, M. W. Tech. Assoc. Papers 24:139(1941); Paper Trade J. 113(10):33 (Sept. 4, 1941).

48. Wells, S. D. and Rue, J. D. U.S. Dept. Agr., Dept. Bull. 1485. May, 1927. 101 p.

49. Nolan, W. J. Tappi 40(3):170-90(March, 1957).

50. Wangaard, F. F., Kellogg, R. M. and Brinkley, A. W., Jr. Tappi Forest Biol. Conf. (Madison), Session 2, Paper 3:60 p. (1965); Tappi 49(6):263-77(June, 1966).

51. Wangaard, F. F., Kellogg, R. M. and Djerf, A. Tappi 50(3):109-14(March, 1967).

52. Wangaard, F. F. and Woodson, G. E. Wood Sci. 5(3):235-40(Jan., 1973).

53. Keller, E. L. and Fahey, D. J. Tappi 51(2): 98-103(Feb., 1968).

54. Schafer, E. R. and Santaholma, M. Tech. Assoc. Papers 17:431(1934); Paper Trade J. 97(19):46 (Nov. 9, 1933).

55. Walker, W. J. Tech. Assoc. Papers 29:379(1937); Paper Trade J. 105(12):44 (Sept. 16, 1937).

56. Keller, E. L. Tappi 33:556-60(1950).

57. Nelson, P. F. and Vanderhoek, N. Appita 31(3): 204-8(Nov., 1977).

58. Chidester, G. H. and Billington, P. S. Tech. Assoc. Papers 20:25(1937); Paper Trade J. 104(6):39 (Feb. 11, 1937).

59. Chidester, G. H. and McGovern, J. N. Tech. Assoc. Papers 23:322(1940); Paper Trade J. 110(10):39 (March 7, 1940).

60. Rommel, G. M. Chem. Met. Eng. 40:197(1933).

61. Nolan, W. J. Tappi 53(7):1309-15(July, 1970).

SOUTH FLORIDA SLASH PINE

Scientific Name *Pinus elliottii* var. *densa* Little & Dorman

Family Name Pinaceae

Range Lower Florida Keys north to Lake Okeechobee and then along both coasts as far north as central Florida. Inland, between the coastal prongs, the varietal and type species ranges overlap.

South Florida slash pine differs from the typical slash pine in several ways: (a) the needles are usually in twos; (b) the seedlings spend several years in a dwarf "grass stage" similar to that of longleaf pine; (c) the trunk divides into large, spreading branches, forming a flat-topped or rounded crown; (d) the wood is very hard and heavy, with very wide summerwood; (e) the tree is typically found on dry, sandy flat lands of limestone outcroppings.

Chemical Composition of Wood.

Proximate Analyses.

	Schwartz & Bray (*1*)
Lignin, %	24.9
C.&B. cellulose, %	58.7
Alpha-cellulose, %	47.6
Pentosans	
Total, %	9.1
In cellulose, %	7.5
Solubility in	
Alcohol-benzene, %	6.4
Ether, %	5.1
1% NaOH, %	14.7
Hot water, %	3.9

Pulping

Kraft. Pulps would undoubtedly be inferior in many respects to pulps prepared from "normal"-growth wood of the southern pines.

Literature Cited

1. Schwartz, S. L. and Bray, M. W. Paper Trade Jour. 113(10): 33(1941).

CARIBBEAN PINE

Scientific Name *Pinus caribaea* Morelet.

Synonyms Nicaraguan pine

Family Name Pinaceae

Range This closely related species to slash pine (*P. elliottii* Engelm.) is native to the Bahama Islands, western Cuba, Isle of Pines, and Central America from British Honduras to eastern Guatemala, northern Honduras, and northeastern Nicaragua.

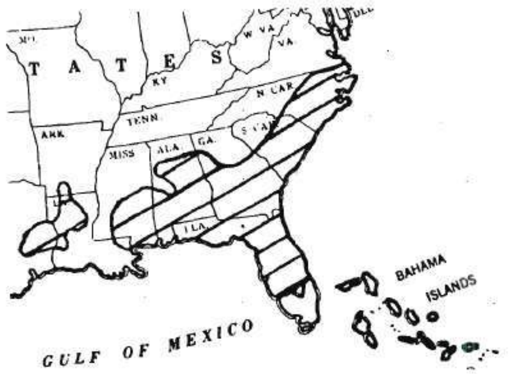
LONGLEAF PINE

Scientific Name *Pinus palustris* Mill.

Synonyms Longleaf yellow pine, southern yellow pine, longstraw pine, hill pine, pitch pine, hard pine, heart pine

Family Name Pinaceae

Range South Atlantic and Gulf Coastal plains. The slash-longleaf pine type occupies about 19 million acres (7.7 million ha) in the Southeast (*1*).



Silvics Longleaf pine is a medium-sized to large tree with a long, clear bole, a small, open crown, and a very deep taproot with many widespreading, well-developed laterals. Although best growth is made on well-drained sandy soils, the tree is found on a variety of sites. In the southern part of its range this species often occupies low ridges or knolls, whereas slash pine is found in the moister depressions. As the tree is very intolerant, pure open stands are typical with a small accumulation of needles or short grasses on the ground. Scrub oaks are common associates on infertile soils. Good seed crops are sporadic. Little height growth occurs during the first three to six years after germination but the roots become strongly developed.

Tree Dimensions 80-120 ft (24-37 m) tall and 2-2.5 ft (61-76 cm) in diameter.

Pathology Resistance to decay: intermediate.

Longleaf pine is relatively resistant to southern fusiform rust (*Cronartium fusiforme*) but seedlings are attacked by the brown spot needle blight (*Scirrhia acicola*). Control of this disease is essential to successful regeneration of longleaf pine. Longleaf pine is also susceptible to the root rot *Heterobasidion annosum* and the heart rots *Phellinus pini* and *Phaeolus schweinitzii.*

The red-headed pine sawfly (*Neodiprion lecontei*) and the pine webworm (*Tetralopha robustella*) often defoliate seedlings. The several species of Ips bark beetles cause the loss of over 100 million board ft (350,000 cubic m) of pine each year (*2*). Longleaf pine is also attacked by the black turpentine beetle (*Dendroctonus terebrans*).

Gross Features of the Wood Similar to loblolly pine.

Microscopic Structure of the Wood See the description for loblolly pine.

Tracheids. Average length, 4.9 mm.

According to Shepard and Bailey (*3*), average fiber length increased outward from the center but fluctuated widely in the outer rings.

A publication relating to coarseness in longleaf pine is Britt (*4*). Other publications on wood ultrastructure and anatomical characteristics of stemwood include Cote and Day (*5*), Howard and Manwiller (*6*) and Dunning (*7*).

Gross Features of the Bark Longleaf pine bark is orange-brown and coarse with thin, papery scales appearing as rough plates on older trees. The narrow, light-colored inner bark, common in southern pines, varies in thickness from about1/16-3/16 in (0.16-0.48 cm), being thickest near the base of the tree. Bark comprises about 12% of the total log volume of longleaf pine.

Microscopic Structure of the Bark

Bark characteristics of all southern hard pines generally overlap.

Periderm. Conspicuous as white lines in the scalelike rhytidome, the long, generally parallel periderms are composed of broad bands of phellem consisting of alternating layers of compactly arranged thin- and thick-walled sclerotic cells, a layer of phellogen and varying layers of phelloderm. The thick-walled phellem cells, about the same size as the ordinary cork cells, are easily identified in tangential sections and macerated tissue by the distinct irregular projections on the cell margins that interlock with adjacent cells in a coglike manner (*8*).

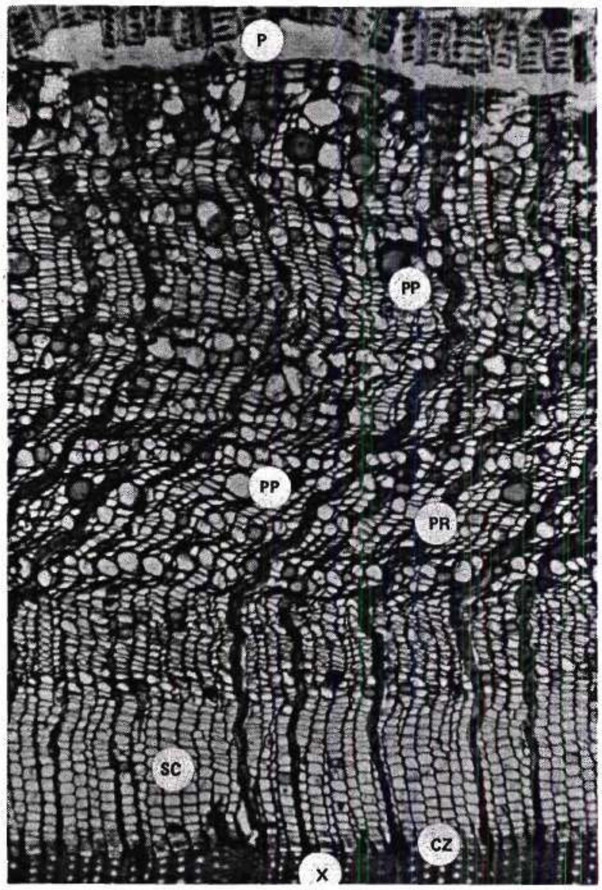
Sieve Cells. The most abundant cellular elements by volume in southern pine phloem, sieve cells are usually aligned in radial rows of about 10 cells and are much longer in longleaf and shortleaf pine than in the other related pine species.

Parenchyma. One to three parenchyma cells, in short radial multiples, form rather irregular tangential lines on cross section and often contain starch, resins, and crystals with rectangular lateral faces.

Rays. Phloem rays, extensions of the radially aligned xylem rays, become distorted and enlarged before reaching the outer part of the inner bark. Rays are mostly uniseriate with some fusiform rays containing horizontal resin canals with well-defined borders of epithelial cells. All ray cells in the phloem have thin, unlignified walls. Erect albuminous cells form the margins on most rays, with no ray tracheids present.

Sclerenchyma. Absent in the secondary phloem.

Publications on bark structure include Crist (*9*), Howard (*8*), Martin (*10*) and Martin and Crist (*11*).



Cross section of longleaf pine wood and bark. Elements depicted include xylem (X), cambium zone (CZ), sieve cells (SC), phloem ray (PR), phloem parenchyma (PP) and a periderm (P). Magnification, 50X.

Physical Properties of Wood

Specific gravity	Green volume	0.54
	Air-dry volume	0.58
	Oven-dry volume	0.62
Density, lb/cu ft (kg/cu m)	Green	55 (881)
	Air-dry	41 (657)
	Oven-dry	39 (625)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	34 (545)

Overall decrease in specific gravity with increase in height of tree (*12*).

Specific gravity increased from north to south in Texas, Alabama, and along the Atlantic coast from North Carolina to central Florida. An east-west trend was also evident (*13*).

Branchwood specific gravity (green volume, oven-dry weight) averaged 0.489 for small, medium and large branches (*14*)

Other publications in this area include Cole, et al. (*15*), Wahlgren and Schumann (*16*), and Zobel, et al. (*17*).

Percent shrinkage, dried to 0% moisture content: r - 5.1, t - 7.5, v - 12.2 (*18*).

Percent moisture content, when green

Green basis	39
Oven-dry basis	63

Percent moisture content, oven-dry basis (*18*)

Heartwood	31
Sapwood	106

An additional publication on moisture content is Cole, et al. (*15*).

Physical Properties of Bark

Specific gravity, green volume	Inner bark	0.25
	Outer bark	0.48
	Total bark	0.45
Density (100% moisture content)	Green weight/ green volume	0.90

Specific gravity, oven-dry weight & volume (*19*) 0.53

Branch bark specific gravity (green volume, oven-dry weight) averaged 0.392 for small, medium and large branches (*14*).

An annotated bibliography on longleaf pine was compiled by Croker (*20*).

Chemical Composition of Wood

Proximate Analyses.

	Chidester et al. (*21*)	F.P.L..	Cole et al. (*22*)	Wise (*23*)
Lignin, %	27.9	–	–	29.1
C. & B. Cellulose, &	58.8	58.5	–	–
Alpha-cellulose, %	44.3	–	–	51.1
Ash, %	–	0.37	–	–
Pentosans				
Total, %	12.4	11.1	–	–
In cellulose, %	10.2	8.87	–	–
Mannan, %	–	4.75	–	–
Acetyl, %	–	0.76	–	–
Methoxyl, %	–	5.05	–	–
Solubility in				
Alcohol-benzene	4.3	–	4.3	5.5
Ether, %	2.9	6.32	–	–
Cold water, %	–	6.20	–	–
Hot water, %	2.4	7.15	–	1.1
1% NaOH, %	11.1	22.4	–	–
Hemicellulose A, %	–	–	–	11.4
Hemicellulose B, %	–	–	–	3.0

Composition of Ash.

K_2O, 10.3; Na_2O, 2.3; CaO, 37.2; MgO, 4.2; P_2O_5, 2.7; SO_3, 4.3; Cl, 0.2; SIO_2, 3.4; Fe_2O_3, 2.8; C, 1.1; CO_2, 31.5%.

Extractives.

For information on heartwood extractives see Lindstedt and Misiorny (*24*). For % composition of extractives, see Drew and Pylant (*25*).

Turpentine and rosin may also be obtained from stumpwood by the steam distillation and solvent processes. These materials have also been investigated intensively. The wood turpentine contains 76% pinene, 9.8% limonene, 8.2% α-terpinene, 4% nopinene, 2% terpinolene, and a trace of γ-terpinene. It contains 20% of the monocyclic terpenes (*26*).

Other investigators report 80% α-pinene, β-pinene, camphene, dipentene, limonene, terpinene, and terpinolene; the nonhydrocarbon portion (about 2%) consists of secondary and tertiary terpene alcohols, aldehydes, phenols, phenolic ethers, and oxidation and polymerization products. Benzaldehyde, furfural, cineole, and sobrerol are present in very small amounts (*27*).

The steam distillate contains, in addition to all the turpentine, part of the pine oil. Steam-distilled pine oil contains small amounts of limonene, dipentene, terpinene, and terpinolene, but is principally a tertiary terpene alcohol, such as α-terpineol; it also contains secondary terpene alcohols, fenchol, and borneol, together with a small amount of a phenol ether, methylchavicol (*28*).

Pinosylvin mono- and dimethyl-ethers are present; also a compound $C_{15}H_{12}O_5$ (probably 2,3-dihydro-3-hydroxychrysin) (*29*).

The wood probably also contains pinobanksin and phenols of the pinosylvin type (Erdtman, *30*).

The ether extract of the sapwood contains 8.3-14.6% and that of the heartwood extract, 10.2-25.2% of unsaponifiable matter. A typical analysis of the saponifiable portion of the sapwood extract gave 34.5% resin acids and 65.5% fatty acids, including 36.1% linoleic acid, 27.8% oleic acid, and 1.6% saturated acids. The unsaponifiable portion contains 31 to 60% of phytosterol. The heartwood extract shows dominance of resin acids over fatty acids and a much lower sterol content in the unsaponifiable portion than the sapwood ether extractives (*31*).

The phytosterol from commercial tall oil is 22,23-dihydrostigmasterol (*32*).

The aqueous extract contains an arabogalactan (*33*).

Tannins are absent (*34*).

For information on ether extractives see Buchanan, et al. (*35a*).

Chemical Composition of Bark

Proximate Analyses.

	Cole, et al. (*22*)
Ash, %	0.6
Calcium, %	0.2
Silica, %	0.004
Alcohol-benzene extractives, %	8.8

Pulping

Kraft. The wood is readily reduced. The pulp is strong, and it is considered a little lower in burst strength and considerably higher in tear strength than northern kraft pulps. The yield is normal. It is used for high-grade wrapping papers and fiberboard (*35b-39*). The resin does not interfere with pulping.

Mechanical. The young, fast-growth wood is suitable for mechanical pulp; however, trouble is caused by pitch. For making light-colored unbleached pulp, the wood must be relatively free of heartwood (*40-42*). Mechanical pulp is used for newsprint and paperboard.

Sulfite. With slight modifications of the standard process, fair pulps can be made with a reasonable bleach consumption, provided young growth or material containing a comparatively small amount of heartwood is used. Heartwood is difficult to pulp. Some pulp is used for dissolving pulp (*43-48*). For hot alkaline sulfite pulping and pulp properties see Ingruber and Allard, (*49*). The resin interferes with pulping. High-quality white paper is made from bleached pulp.

Utilization of Wood and Bark

Use properties of wood. The wood is very hard, resinous, heavy, and tough. Nail-holding ability is intermediate. The heartwood of dense wood is high in decay resistance. The sapwood is not durable and can be treated with preservatives.

Calorific value of wood. Heating value 7885 Btu/lb (4381 kg cal/kg) air dry.

Calorific value of bark.	Btu/ovendry lb	9,290
	kcal/kg	5,162
	Btu/ft^3	258,801
	$kcal/m^3$	1,845

Chemical uses of wood. The wood is used for turpentine and rosin; it is used in distillation and extraction processes for the production of pine oil, pine tar, and other products. The yield from steam distillation is: 6.5 gallons of turpentine, 6.2 gallons of pine oil, and 350 pounds of rosin per ton of stumpwood or 27.1 liters of turpentine, 25.9 liters of pine oil and 61.2 kg of rosin per metric tone of stumpwood.

Other uses of wood. The wood is used for pulpwood, for building construction of all kinds, railway ties, poles, cooperage, veneer, piling, excelsior, fuelwood, posts, and mine timbers.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 445, 1973, 114 p.
2. USDA, Forest Service. Forest Pest Leaflet No. 129, 1971, 7 p.
3. Shepard, H. B. and Bailey, I. W. Proc. Soc. Am. For. 9:522-5(1914).
4. Britt, K. W. Tappi 48(1):7-11(1965).
5. Cote, W. A. and Day, A. C. State Univ. Coll. of Forestry at Syracuse Univ. Tech. Publ. No. 95, 1969, 70 p.
6. Howard, E. T. and Manwiller, F. G. Wood Sci. 2(2): 77-86(1969).
7. Dunning, C. E. Tappi 52(7):1326-41 (1969).
8. Howard, E. T. Wood Sci. 3(3):134-48 (1971).

9. Crist, J. B. Dissertation Abstracts B(1972) 33(3):983-4.

10. Martin, R. E. Forest Prod. Jour. 19(8): 23-30 (1969).

11. Martin, R. E. and Crist, J. B. Wood & Fiber 2(3): 269-79 (1970).

12. Okkonen, E. A., Wahlgren, H. E. and Maeglin, R. R. Forest Prod. Jour. 22(7):37-42(1972).

13. Saucier, J. R. and Taras, M. A. USDA, Forest Serv. Res. Pap. No. SE-45, 1969, 16 p.

14. Phillips, D. R., Clark, A., III and Taras, M. A. Wood Sci. 8(3):164-9(1976).

15. Cole, D. E., Zobel, B. J. and Roberds, J. H. Tappi 49(4): 161-6(1966).

16. Wahlgren, H. E. and Schumann, D. R. USDA, Forest Serv. Res. Pap. No. FPL-176, 1975.

17. Zobel, B. J., Kellison, R. C., Matthias, M. F. and Hatcher, A. V. NC Agric. Expt. Sta., Tech. Bull. No. 208, 1972, 56 p.

18. USDA, Forest Service. Forest Prod. Laboratory. Agriculture Handbook No. 72, 1974.

19. Harkin, J. M. and Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.

20. Croker, T. C., Jr. USDA, Forest Serv. Res. Pap. SO-35, 1968, 52 p.

21. Chidester, G. H., McGovern, J. N. and McNaughton, G. C. Tech. Assoc. Papers 21:264(1938); Paper Trade J. 107(4):36(July 28, 1938).

22. Cole, D. E., Zobel, B. J. and Roberds, J. H. Tappi 49(4):161-6)April, 1966).

23. Wise, L. E. Private communication.

24. Lindstedt, G. and Misiorny, A. Acta Chem. Scand. 5:121-8(1951).

25. Drew, J. and Pylant, G. D., Jr. Tappi 49(10):430-8(Oct., 1966).

26. Dupont, G., Rambaud, –, and Binochon, – Bull. Inst. Pin. 1935:121.

27. Palkin, S., Chadwick, T. C. and Matlack, M. B. U.S. Dept. Agr., Tech. Bull. 596. 1937. 29 p.

28. Palmer, R. C. Ind. Eng. Chem. 26:703 (1934).

29. Erdtman, H. Svensk Papperstidn. 46:226 (1943).

30. Erdtman, H. Svensk Kem. Tid. 56:95(1944).

31. Kurth, E. F. Ind. Eng. Chem. 24:192 (1933).

32. Marker, R. E. and Whittle, E. L. J. Am. Chem. Soc. 59:2704(1937).

33. Foreman, E. L. and Englis, D. T. Ind. Eng. Chem. 23:415(1931).

34. Russell, A. J. Am. Leather Chemists Assoc. 38: 235(1943).

35a. Buchanan, M. A., Sinnett, R. V. and Jappe, J. A. Tappi 42:578-83(1959).

35b. Bray, M. W. and Curran, C. E. Paper Trade J. 96(6): 30(1933).

36. Bray, M. W. and Curran, C. E. Tech. Assoc. Papers 21:458(1938); Paper Trade J. 105(20):39(Nov. 11, 1937).

37. Bray, M. W., Martin, J. S. and Schwartz, S. L. Tech. Assoc. Papers 21:441(1938); Paper Trade J. 104(24):39(Dec. 9, 1937).

38. Rasch, R. H. Paper Ind. 17:948(1936).

39. Wells, S. D. and Rue, J. D. U.S. Dept. Agr., Dept. Bull. 1485. May, 1927. 101 p.

40. Fuller, A. C. and Carpenter, C. Tech. Assoc. Papers 21:438; Paper Trade J. 107(9):30(Sept. 1, 1938).

41. MacNaughton, W. G. Paper Mill News 58(29):9(1935).

42. Walker, W. J. Tech. Assoc. Papers 20:379 (1937); Paper Trade J. 105(12):44(Sept. 16, 1937).

43. Carpenter, C. and McCall, F. Ind. Eng. Chem. 30:15 (1938).

44. Chidester, G. H. and McGovern, J. N. Tech. Assoc. Papers 23:322(1940); Paper Trade J. 110(10):39 (March 7, 1940).

45. McKee, R. H. and Cable, D. E. Paper Trade J. 80(17):41(April 23, 1925).

46. MacNaughton, W. G. Paper Mill News 58(29):9 (1935).

47. MacNaughton, W. G. and Allen, W. F. Paper Trade J. 97(2):36(1933).

48. Rasch, R. H. Paper Ind. 17:948(1936).

49. Ingruber, O. V. and Allard, G. A. TAPPI/CPPA Intern. Sulfite Pulping Recovery Conf. (Boston), Oct.-Nov., 1972: 331-62.

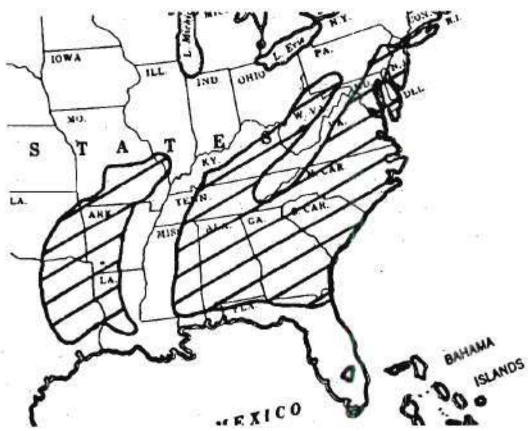
SHORTLEAF PINE

Scientific Name *Pinus echinata* Mill.

Synonyms Shortleaf yellow pine, southern yellow pine, yellow pine, shortstraw pine, Arkansas pine

Family Name Pinaceae

Range 22 states in the southeastern United States. The loblolly-shortleaf pine type covers about 58 million acres (23.5 million ha) in the south (*1*).



Silvics The tree is medium sized to large with a clear, well-formed bole, a small, narrowly pyramidal crown, and a very deep tap root. This species is most common in pure or mixed stands on dry, upland soils. Common associates are loblolly pine, Virginia pine, eastern red cedar, various oaks, and mockernut hickory. On moister soils, it is frequently associated with sweetgum and bitternut hickory. Seed is produced annually with good crops at 3-6 yr intervals. Young trees sprout readily from the root collar after destruction by fire or cutting. The species is rated as intolerant.

Tree Dimensions 80-100 ft (24-30 m) tall and 2-3 ft (61-91 cm) in diameter on good sites. A fully stocked stand will yield from 49-57 cords (including bark) of pulpwood per acre (309-359 m^3/ha) at age 35 on areas with site indexes of 70-80 ft (21-24 m) (*2*).

Pathology Resistance to decay: intermediate

Phytophthora cinnomomi, as part of the littleaf disease complex, is responsible for widespread mortality. The littleaf disease, a major obstacle to management of shortleaf pine, is caused by a combination of heavy soil, periodic excessive moisture and moisture deficit and attack by *Phytophthora cinnomomi* (*2*). No practical control measures have been found for natural stands. The development of resistant strains of shortleaf pine may be one answer. The species is fire resistant and windfirm.

Shortleaf pine is among the more favored species for attack by the southern pine beetle (*Dendroctonus frontalis*). Outbreaks appear to be caused by a combination of conditions which reduce the vigor of trees and, at the same time, increase the size and vigor of the beetle population. Shortleaf pine is also attacked by the black turpentine beetle (*Dendroctonus terebrans*) and several species of Ips bark beetles. Various species of pine sawfly (*Neodiprion* spp.) defoliate trees of all sizes and can cause serious growth losses.

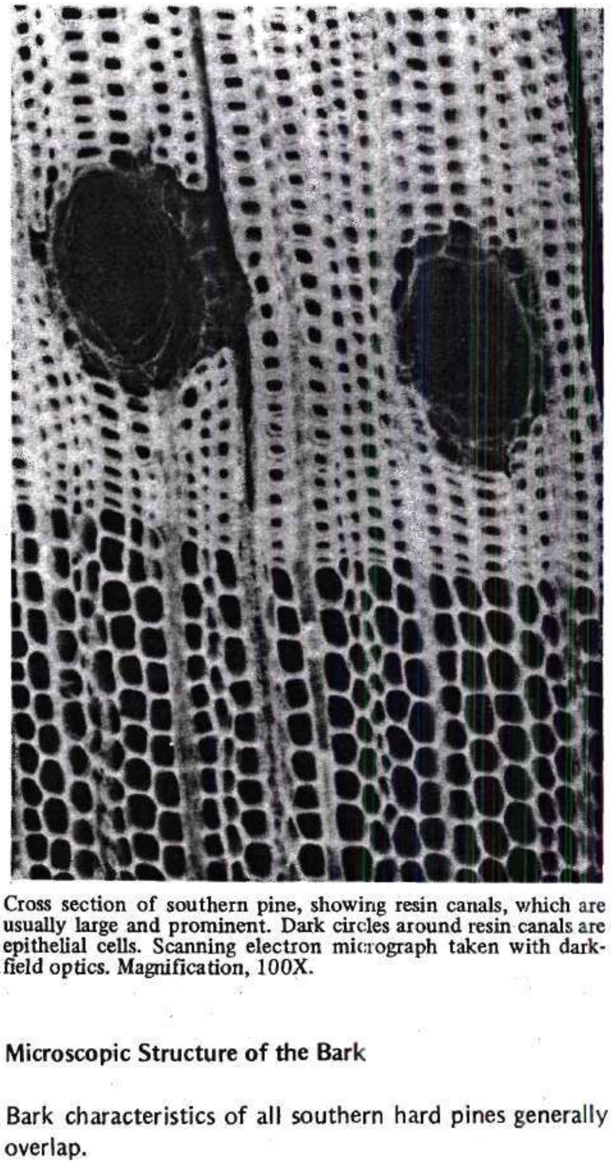
Gross Features of the Wood Similar to loblolly pine.

Microscopic Structure of the Wood See the description for loblolly pine.

Tracheids. Average length, 4.6 mm.

In shortleaf pine latewood, the cell wall thickness is 10.2 µm and the lumen diameter is 13.1 µm. According to Burkart and Watterson (*3*), the ratio of carbohydrate/noncarbohydrate cell wall material in shortleaf pine is apparently influenced more by the ratio earlywood/latewood than by site quality. A publication relating to coarseness in shortleaf pine is Britt (*4*). Other publications on wood ultrastructure and anatomical characteristics of stemwood include Cote and Day (*5*) and Howard and Manwiller (*6*).

Gross Features of the Bark Shortleaf pine bark, comprising about 12% of the total log volume, is nearly black and roughly scaly on small trees, later exfoliating into deep fissures with comparatively thin scales on the surface and with many small resin pockets scattered through the corky layers. In the rhytidome, the secondary phloem tissues, conspicuously expanded in the newly formed layers, are reddish brown in color and isolated by light-colored periderm lines in a yellowish hue. The inner bark, about 1/16 inch (0.16 cm) wide, is lighter in color, and resin canals are inconspicuous.



Cross section of southern pine, showing resin canals, which are usually large and prominent. Dark circles around resin canals are epithelial cells. Scanning electron micrograph taken with dark-field optics. Magnification, 100X.

Microscopic Structure of the Bark

Bark characteristics of all southern hard pines generally overlap.

Periderms. Generally parallel to one another in most parts of the rhytidome, periderms are composed of a rather broad phellem, a layer of phellogen, and ca. 2-4 layers of phelloderm. A band of ordinarily thin-walled typical phellem cells often occurs in alternation with a band of thick-walled cells which were probably transformed from phelloderm. Periderm cells are usually rectangular in cross section, about 50 μm in tangential dimension and 30 μm in radial dimension. Cell walls are slightly thicker in the last-formed phelloderm than in the ordinary corky phellem. Phellem and phelloderm cells often contain "resinous" substances. Remnants of the phloem lie to the outside of each periderm, and the expanded parenchyma cells or phelloderm cells occupy much of the area between the periderms.

Inner Bark. Composed of sieve cells, parenchyma and phloem rays.

Sclerenchyma. Absent in the secondary phloem.

Sieve Cells. Regularly aligned in continuous radial rows and interspersed by a layer of parenchyma, are rectangular in cross section, about 30-50 μm and 20-30 μm in tangential and radial dimensions, respectively. Length, usually about 3.6-5.0 mm, varies in different specimens. Sieve cells in *P. echinata* and *P. palustris* are much longer than those in other hard pines (*7*).

Parenchyma. Parenchyma strands, about the same length as the adjacent sieve cells, consist of 1-3 cells in short radial rows aligned more or less tangentially in continuous lines in cross section. Individual cells often contain large prismlike crystals, starch grains and "resinous" substances. About the same size as sieve cells in cross section, parenchyma become broader at the outer part of the inner bark and are conspicuously expanded in the outer bark, occupying most of the rhytidome layers, and the cell walls become lignified.

Rays. Similarly expanding and enlarged in the rhytidome, phloem rays are of two types. Uniseriate rays are comparatively low, 8 or fewer cells or about 250 μm. Conspicuous albuminous cells, twice as high as a regular ray cell, appear at every ray section close to the cambium. Ordinary individual ray cells are about 80-100 μm in radial dimension and 20-30 μm high and contain rather abundant starch grains. Fusiform rays, usually about 70 μm wide and 500 μm high on tangential section, contain horizontal resin canals lined with usually 3-4 epithelial cells. Publications on bark structure include Howard (*8*), Martin (*9*), and Martin and Crist (*10*).

Physical Properties of Wood

Specific gravity	Green volume	0.46
	Air-dry volume	0.51
	Oven-dry volume	0.54
Density, lb/cu ft (kg/cu m)	Green	52 (833)
	Air-dry	36 (577)
	Oven-dry	34 (545)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	29 (464)

Overall decrease in specific gravity with increase in height of tree (*11*).

Unlike other major southern pine species examined, shortleaf pine did not exhibit an overall north-south or east-west geographic trend in specific gravity in the South (*12*). However, Gilmore (*13*) reported that specific gravity decreased northward from southern Mississippi into southern Illinois due to either physiographic and/or climatic factors but not geographic race.

According to Gilmore (*14*) studies on wood from plantations aged 13-28 years within a N-S range of 100 miles showed that latewood percent accounted for 36% of the variation in specific gravity. In a study by Thor and Bates (*15*), only a small amount of total variation in wood properties was accounted for by site characteristics.

Branchwood specific gravity (green volume, o.d. weight) averaged 0.450 for small, medium and large branches (*16*).

An additional publication on wood density *vs.* ring growth is Ralston and McGinnes (*17*). Other publications in this area include Wahlgren and Schumann (*18*) and Zobel, et al. (*19*).

Percent shrinkage, dried to 0% moisture content: r - 4.4, t - 7.7, v - 12.3.

Percent moisture content, when green	
Green basis	45
Oven-dry basis	81

Percent moisture content, oven-dry basis (*20*)	
Heartwood	32
Sapwood	122

Physical Properties of Bark

Specific gravity, green volume	Inner bark	0.26
	Outer bark	0.35
	Total bark	0.35
Density (100% moisture content)	Green weight/ green volume	0.72
Specific gravity (*21*) oven-dry weight and volume		0.49

Branchbark specific gravity (green volume, o.d. weight) averaged 0.356 for small, medium and large branches (*16*).

Chemical Composition of Wood

Proximate Analyses.

	Chidester et al. (*22*)	Institute Paper Chemistry, Project 3212, Report 6	Howard (*23*)
Lignin, %	26.4	–	–
C. & B. cellulose, %	62.2	–	–
Alpha-cellulose, %	47.2	–	–
Pentosans			
Total, %	12.1	–	–
In cellulose, %	9.5	–	–
Solubility in			
Alcohol-benzene, %	3.0	4.1	–
Ether, %	2.3	–	2.64
1% NaOH, %	11.2	–	–
Hot water, %	2.1	–	–
Toluene, %	–	–	3.38

Analysis of sapwood by Wise (*24*)

Alcohol-benzene extractives, %	4.8
Hot-water extractives, %	1.2
Lignin, %	27.5
Alpha-cellulose (chlorite method), %	53.1
Hemicellulose A, %	10.2
Hemicellulose B, %	3.4

Kurth and Sherrard (*25*) found the alcohol-benzene solubles content of wood to be 3.3-6.3%; the sapwood contained 2.6% ether solubles, while the heartwood contained 5.7% ether solubles.

Extractives. The distribution of the ether and alcohol-benzene extractives in a tree is not uniform. Of the ether extract of the sapwood 6.4 to 14.6% was unsaponifiable, and of the heartwood extract 17.0 to 30.8% was unsaponifiable. A typical analysis of the sapwood extract gave 24.7% of resin acids and 75.3% of fatty acids, including 32.1% linoleic acid, 40.9% oleic acid, and 2.3% saturated fatty acids. The unsaponifiable portion contains 35 to 64% sterol. Less detailed data are given for the heartwood extract; resin acids predominate, and the sterol content of the unsaponifiable portion is much lower than in the sapwood (*25*).

Alcohol-benzene extractives, 4.8%; water extractives (after alcohol-benzene), 1.2% (*27*).

For percent composition of extractives, see Drew and Pylant (*28*); heartwood extractives, Lindstedt and Misiorny, (*29*). For resin acids, free fatty acids and unsaponifiables, see Kurth and Sherrard (*25*) and Buchanan, et al. (*30*).

Chemical Composition of Bark

Proximate Analyses.

	Project 3212, Report 6	Koch (*31*)
Ash content, %	1.6	0.7
Calcium content, %	0.4	--
Silica content, %	0.1	--
Alcohol-benzene extractives, %	7.7	--

For information on elements in bark, see Harder and Einspahr (*32*).

Pulping.

Kraft. The wood is readily reduced to a fairly strong pulp, and yield is normal. The pulp is used for high-grade wrapping papers, fiberboard, and book stock (*33-36*).

Mechanical. The young, fast-growth wood is suitable and is readily reduced. It is pitchy. It requires 50% more power than does white spruce. Its use is limited chiefly by the content of pitch (*36, 37*). Groundwood is used chiefly for fiberboard, newsprint, and paperboard.

Cold soda. Produced good insulation board stock with fair color (yellowish), (*40*).

NSSC. Chidester (*38*), reports a pulp yield of 78% with a lignin content of 20.3%; he also gives information on mechanical properties of paper.

Sulfite. With slight modifications of the standard process, fair pulps can be made with a reasonable bleach consumption, provided young growth or the material containing a comparatively small amount of heartwood is used; heartwood is difficult to pulp; the yield is normal. (*36, 39*). Some sulfite pulp is used for viscose rayon. High quality white paper is made from bleached sulfite pulp.

Utilization of Wood and Bark.

Use properties of wood. The wood is hard, heavy, durable, stiff, strong, and tough. It does not split easily and takes paint well. Nail-holding ability is intermediate. It is comparatively soft and light in weight and has little resin. The heartwood is intermediate in durability, while the sapwood is not durable and can be treated with preservatives.

Calorific value of wood. 7885 Btu/lb air dry (4381 kcal/kg)

Calorific value of bark.

Btu/o.d. lb 9,310
kcal/kg 5,173

Btu/ft^3 205,574
kcal/m^3 1,466

Other uses of wood. The wood is used for building construction of all kinds, railway ties, poles, cooperage, veneer, and piling; also excelsior, fuelwood, posts, and mine timbers.

Other uses of bark. Bark is used as poultry litter (*41*), as are planer shavings.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 445, 1973. 114 p.
2. USDA, Forest Service. Agriculture Handbook No. 271, 1965. 762 p.
3. Burkart, L. F. and Watterston, K. G. Forest Prod. Jour. 18(5):25-8(1968).
4. Britt, K. W. Tappi 48(1):7-11(1965).
5. Cote, W. A. and Day, A. C. State Univ. Coll. of Forestry at Syracuse, Univ. Tech. Publ. No. 95, 1969. 70 p.
6. Howard, E. T. and Manwiller, F. G. Wood Sci. 2(2): 77-86 (1969).
7. Chang, Y. P. USDA Tech. Bull. No. 1095, 1954. 86 p.
8. Howard, E. T. Wood Sci. 3(3):134-48 (1971).

9. Martin, R. E. Forest Prod. Jour. 19(8): 23-30 (1969).

10. Martin, R. E. and Crist, J. B. Wood & Fiber 2(3): 269-79(1970).

11. Okkonen, E. A., Wahlgren, H. E. and Maeglin, R. R. Forest Prod. Jour. 22(7):37-42(1972).

12. Saucier, J. R. and Taras, M. A. USDA, Forest Serv. Res. Pap. No. SE-45, 1969. 16 p.

13. Gilmore, A. R. Jour. Forestry 61(8):596-7 (1963).

14. Gilmore, A. R. Trans. Ill. St. Acad. Sci. 63(4): 366-9(1970).

15. Thor, E. and Bates, A. L. Tappi 53(2):290-4 (1970).

16. Phillips, D. R., Clark, A., III and Taras, M. A. Wood Sci. 8(3):164-9(1976).

17. Ralston, R. A. and McGinnes, E. A., Jr. So. Lumberman, April 1, 1964. pp. 17-19.

18. Wahlgren, H. E. and Schumann, D. R. USDA, Forest Serv. Res. Pap. No. FPL-176, 1975.

19. Zobel, B. J., Kellison, R. C., Matthias, M. F. and Hatcher, A. V. NC Agric. Expt. Sta., Tech. Bull. No. 208, 1972. 56 p.

20. USDA, Forest Prod. Laboratory. Agriculture Handbook No. 72. 1974.

21. Harkin, J. M. and Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969. 41 p.

22. Chidester, G. H., McGovern, N. N. and McNaughton, G. C. Tech. Assoc. Papers 21:264(1938); Paper Trade J. 107(4):36(July 28, 1938).

23. Howard, E. T. U.S. Forest Serv., Res. Note S50-204. 4 p. (1976).

24. Wise, L. E. Private communication.

25. Kurth, E. F. and Sherrard, E. C. Ind. Eng. Chem. 23:1156 (1931); 24:1179(1932); 25:192(1933).

26. Kurth, E. F. Ind. Eng. Chem. 24:192(1933).

27. The Institute of Paper Chemistry. Unpublished data.

28. Drew, J. and Pylant, G. D., Jr. Tappi 49(10): 430-8(Oct., 1966).

29. Lindstedt, G. and Misiorny, A. Acta Chem. Scand. 5:121-8(1951).

30. Buchanan, M. A., Sinnett, R. V. and Jappe, J. A. Tappi 42:578-83(1959).

31. Koch, P. Utilization of the southern pines. Vol. I: The raw material. USDA, Forest Serv. Agriculture Handbook No. 420, 1972. 734 p.

32. Harder, M. L. and Einspahr, D. W. To be submitted to Tappi.

33. Bray, M. W. and Curran, C. E. Tech. Assoc. Papers 21:458(1938); Paper Trade J. 105(20):39(Nov. 11, 1937).

34. Bray, M. W., Martin, J. S. and Schwartz, S. L. Southern Pulp Paper J. 2(6):35(1939).

35. Martin, J. S. Southern Pulp Paper J. 6(7):13 (1943).

36. Wells, S. D. and Rue, J. D. USDA Dept. Bull. 1485. May, 1927. 101 p.

37. Wynne-Roberts, R. I. Tech. Assoc. Papers 20:258 (1937); Paper Trade J. 104(6):46 (Feb. 11, 1937).

38. Chidester, G. H. Proc. Forest Products Research Soc. 3:197(1949).

39. Chidester, G. H. and McGovern, J. N. Tech. Assoc. Papers 23:322(1940); Paper Trade J. 110(10): 39(March 7, 1940).

40. Eberhardt, L. Tappi 44(10):203A-207A(1961).

41. Laborsky, P., Jr., Holleman, K. A. and Dick, J. W., p. 150-159 in Mater, J. and Mater, M. H., Forest Products Research Society. (Madison, WI 53705), Proc. No. P-75/75-15: 177 p. (1976).

VIRGINIA PINE

Scientific Name *Pinus virginiana* Mill.

Synonyms Scrub pine, Jersey pine, North Carolina pine, spruce pine

Family Name Pinaceae

Range Appalachians and adjacent regions.

Silvics Virginia pine is a relatively small tree with persistent branches and a shallow, widespreading root system at maturity. It will thrive only in moderately well-drained to well-drained soils, but will grow on poor, dry soils. Abandoned farm lands often support pure stands. Seed is produced in abundance and shows a high percentage of germination. The principal tree associates are shortleaf pine, white, chestnut, southern red, black, and scarlet oaks, sweetgum, red maple, and black tupelo. This species is rated as intolerant.

Tree Dimensions 50-75 ft (15-23 m) tall and 12-15 inch (30-38 cm) in diameter.

Pathology

The heart rot, *Phellinus pini*, is generally not important in stands under 50 years of age (*1*). The pine is attacked by several rusts (*Cronartium* spp.) but none are serious. Other rots infecting Virginia pine include the root rot, *Heterobasidion annosum* and the butt rot (*Phaeolus schweinitzii*).

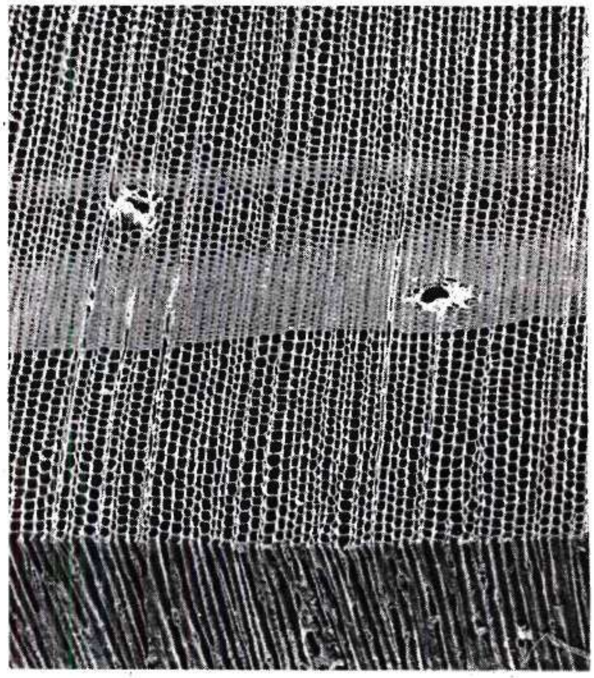
The southern pine beetle (*Dendroctonus frontalis*) is a serious pest, and Virginia pine is a highly preferred species for attack by the beetle. In the mid-Atlantic states, Virginia pine is also a favored species for infestation by the Nantucket pine tip moth (*Rhyacionia frustrana*). The larvae of the Virginia pine sawfly (*Neodiprion pratti pratti*) consume needles, portions of developing buds and the bark of twigs. The pine engravers (*Ips* spp.) also damage Virginia pine significantly during periodic increases in their numbers.

Gross Features of the Wood Similar to loblolly pine.

Microscopic Structure of the Wood See the description for loblolly pine.

Tracheids. Average length, 2.1 mm.; average diameter, 35-45 μm. Weight factor (unbleached kraft) of 1.00 and coarseness of 17.0 mg/100 m.

A publication relating to tracheid length variation in trees located in Kentucky and Tennessee is Thor (*2*). A publication on wood ultrastructure is Cote and Day (*3*).



Cross sectional and tangential views of Virginia pine, showing portions of two growth rings and abrupt transition between earlywood and latewood. A false growth ring is also depicted. Magnification 35X.

Gross Features of the Bark The dark brown bark of Virginia pine is thin and smooth, making this species particularly vulnerable to fires. At 20 ft (6 m) or more above ground, the bark ranges from 0.05-0.1 in (0.13-0.25 cm) on trees with dbh of 5 in (13 cm) or larger. The thin, smooth bark, an indicator of fast growth, eventually exfoliates into scaly plates. Warner and Goebel (*4*) give bark volume tables for small-diameter Virginia pine.

Microscopic Structure of the Bark

Bark characteristics of all southern hard pines generally overlap.

Rhytidome. Consists of alternate layers of old periderm and dead, obliterated phloem.

Periderms. They are rather broad and composed of: (a) a layer of phellogen or cork cambium, (b) several layers of expanded and unexpanded phelloderm cells of varying size, and (c) phellem cells consisting of thin-walled cork cells which usually alternate with thick-walled sclerified stone cells. The proportions of each tissue vary within a single cross section.

Sieve Cells. Aligned in radial rows of up to 10 cells, interspersed by 1-3 parenchyma cells in short radial multiples, forming irregular tangential lines on cross section. These two types of cells are bordered radially by uniseriate and fusiform rays. The uncollapsed sieve cells near the cambium zone average approximately 35-40 μm tangentially and 25-30 μm radially.

Parenchyma. Parenchyma cells enlarge greatly in the transformation from inner bark to rhytidome and occupy a large area of a rhytidome layer. Styloid crystals, composed of calcium oxalate (*5*), are found in the lumina of many parenchyma cells in the inner bark (tangential section).

Rays. Uniseriate rays are low, usually less than 8 cells or less than 200 μm in height. Fusiform rays are usually about 70-80 μm in width and 400 μm high on tangential section and contain resin canals.

Sclerenchyma. Absent in the secondary phloem.

Publications on bark structure include Howard (*5*), Martin (*6*), and Martin and Crist (*7*).

Physical Properties of Wood

Specific gravity	Green volume	0.45
	Air-dry volume	0.48
Density, lb/cu ft (kg/cu m)	Oven-dry	26 (416)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	28 (448)

Overall decrease in specific gravity with increase in height of tree (*8*).

Virginia pine showed no apparent geographic trends in specific gravity (*9*).

Other publications on specific gravity include Rink and Thor (*10*), Smith and Wahlgren (*11*), and Zobel, et al. (*12*).

Percent moisture content, when green	
Green basis	47
Oven-dry basis	88

Physical Properties of Bark

Specific gravity, green volume	Inner bark	0.27
	Outer bark	0.56
	Total bark	0.54
Specific gravity, oven-dry weight & volume (*13*)		0.63
Density (100% moisture content)	Green weight/ green volume	1.03

Chemical Composition of Wood

Proximate Analyses. Alcohol-benzene extractives, 4.1% (Institute Paper Chemistry, Project 3212, report 6). Benzene extractives 1.18-1.36%; alcohol extractives (after benzene), 0.98-1.30% (*14*). Ether solubles are 2.5% of whole wood (*15*).

Extractives. Tannin is absent (*16*). Pinobanksin, pinocembrin, pinosylvin monomethyl ether, and L-arabinose are found in the heartwood (*17, 18*). Buchanan et al. (*15*) found the composition of ether extractives to be 44% resin acids, 9% free fatty acids, 40% fats, and 7% unsaponifiables. For other information on extractives see Lindstedt and Misiorny (*18*).

Chemical Composition of Bark

Proximate Analysis.

	Institute Paper Chemistry, Project 3212, report 6
Ash, %	2.2

Calcium, %	0.7
Silica	0.01
Alcohol-benzene extractives, %	8.2

For information on elements in bark, see Harder and Einspahr (*19*).

Pulping

Groundwood. The wood is readily reduced and pitchy. It requires 50% more power than does white spruce. For making light-colored unbleached groundwood pulp the wood must be relatively free of heartwood (*20*).

Kraft. The wood is readily reduced and makes strong pulp. The yield is normal. It is used for high-grade wrapping paper, fiberboard, and book stock (*20, 21*). A high-yield unbleached pulp is made with green liquor. Sack papers, corrugating medium, and linerboard are made from the pulps.

Sulfite. With slight modifications of the standard process, the wood can be made into fair pulps with a reasonable bleach consumption, provided young growth or material containing a comparatively small amount of heartwood is used; heartwood is difficult to pulp (*20, 22*).

Thermomechanical. The wood is used with *Pinus taeda* for thermomechanical pulp.

Utilization of Wood and Bark

Use properties of wood. The wood is moderately light in weight, weak, moderately low in stiffness, moderately soft, and moderately low in shock-resisting ability.

Calorific value of bark

Btu/oven-dry lb 9,170
kcal/kg 5,095

Btu/ft^3 309,029
kcal/m^3 2,203

Other uses of wood. The wood is used for boxes, ties, charcoal, and fencing.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 271, 1965. 762 p.

2. Thor, E. Jour. Forestry 62(4):258-62(1964).

3. Cote, W. A. and Day, A. C. State Univ. Coll. of Forestry at Syracuse Univ. Tech. Publ. No. 95, 1969. 70 p.

4. Warner, J. R. and Goebel, N. B. South Carolina Agric. Expt. Sta. For. Res. Ser. No. 9, 1963. 12 p.

5. Howard, E. T. Wood Sci. 3(3):134-48(1971).

6. Martin, R. E. Forest Prod. Jour. 19(8):23-30 (1969).

7. Martin, R. E. and Crist, J. B. Wood & Fiber 2(3):269-79(1970).

8. Okkonen, E. A., Wahlgren, H. E. and Maeglin, R. R. Forest Prod. Jour. 22(7):37-42(1972).

9. Saucier, J. R. and Taras, M. A. USDA, Forest Serv. Res. Pap. No. SE-45, 1969. 16 p.

10. Rink, G. and Thor, E. In Proc., 12th So. For. Tree Improv. Conf., 1973, pp. 24-30.

11. Smith, D. M. and Wahlgren, H. E. Tappi 54(1):60-2(1971).

12. Zobel, B. J., Kellison, R. C., Matthias, M. F. and Hatcher, A. V. NC Agric. Expt. Sta., Tech. Bull. No. 208, 1972. 56 p.

13. Harkin, J. M. and Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969. 41 p.

14. McKee, R. H. and Cable, D. E. Paper Trade J. 77, (16):101(Oct. 18, 1923).

15. Buchanan, M. A., Sinnett, R. V. and Jappe, J. A. Tappi 42:578-83(1959).

16. Russell, A. J. Am. Leather Chemists Assoc. 39:173 (1944).

17. Lindstedt, G. Acta Chem. Scand. 3:1381(1949).

18. Lindstedt, G. and Misiorny, A. Acta Chem. Scand.

5:121-8(1951).

19. Harder, M. L. and Einspahr, D. W. To be submitted to Tappi.

20. Wells, S. D. and Rue, J. D. USDA, Dept. Bull. 1485. May, 1927. 101 p.

21. Hill, E. H. Tech. Assoc. Papers 27:267(1944); Paper Trade J. 119, (19):27(1944).

22. Rommel, G. M. Chem. Met. Eng. 40:197(1933).

SAND PINE

Scientific Name *Pinus clausa* (Chapm. ex Engelm.) Vasey ex Sarg.

Synonyms Scrub pine, spruce pine

Family Name Pinaceae

Range Central Florida and northwestern Florida.

Silvics A relatively small tree, often of poor form, commonly found on light, sandy, infertile soil. In central Florida its habit of retaining many of its cones unopened for several years enables it to seed in large numbers following fire. The type with sand pine predominant occurs on very dry, high sand ridges and coastal dunes. Its chief associates are myrtle oak, Florida hickory, and Chapman white oak. On ground intermittently wet, this species is found in mixture with longleaf, slash, and loblolly pines, southern- and pond-cypresses, and black and water tupelos. Two races of sand pine exist, the Ocala race with closed cones and the Choctawhatchee race with open cones.

Tree Dimensions 60 ft (18 m) tall and 1 ft (30 cm) in diameter at maturity.

Pathology Resistance to decay: intermediate.

The heart rot, *Phellinus pini,* can cause considerable damage to mature trees, particularly if branch stubs are present. The round galls (*Cronartium quercuum*) are common but do little damage. Root rots and fungi attacking sand pine include *Clitocybe tabescens, Heterobasidion annosum* and *Phaeolus schweinitzii.*

Insects attacking sand pine include the black turpentine beetle (*Dendroctonus terebrans*), the southern pine beetle (*D. frontalis*), and Ips engraver beetles. These are particularly prevalent on injured or weakened trees. The pitch moth larvae (*Dioryctria* sp.) damage cones and twigs of sand pine, and the red-headed pine sawfly (*Neodiprion lecontei*) is an occasional defoliator.

Gross Features of the Wood Similar to loblolly pine.

Microscopic Structure of the Wood

See the description for loblolly pine.

Tracheids. Average length, 3.9 mm.

Gross Features of the Bark Gray, relatively smooth.

Microscopic Structure of the Bark *(1)*

Rhytidome. Scalelike, with conspicuous periderm composed of both thin- and thick-walled cells.

Sclerenchyma. Absent in the secondary phloem.

Sieve Cells. Often in radial rows of about 10 cells.

Rays. Fusiform rays common.

Parenchyma. Often 1 to 3 parenchyma cells in a short radial multiple, forming rather irregular tangential lines on cross section of the inner bark, and containing crystals with rectangular lateral faces.

Physical Properties of Wood.

Specific gravity	Green volume	0.45
	Air-dry volume	0.48
	Oven-dry volume	0.51
Density, lb/cu ft (kg/cu m)	Green	38 (609)
	Air-dry	34 (545)
	Oven-dry	32 (513)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	28 (448)

Percent shrinkage, dried to 0% moisture content: r - 3.9, t - 7.3, v - 10.0

Percent moisture content, when green

Green basis	26
Oven-dry basis	36

Specific gravity, green volume and oven-dry weight (2)	Earlywood	Latewood
Choctawhatchee	0.35	0.66
Ocala	0.27	0.58

Chemical Composition of Wood

Proximate Analysis.

	F.P.L. (*3*)
Lignin, %	27.2
C. & B. cellulose, %	61.0
Alpha-cellulose, %	42.9
Pentosan, total %	6.9
Solubility in	
Alcohol-benzene, %	2.2
Ether, %	1.1
1% NaOH	11.8
Hot water, %	2.5

Extractives. Pinocembrin, pinobanksin, pinsylvin, pinosylvin monomethyl ether, and L-arabinose are present (*4, 5*). One sample also contained pinostrobin and 3,5-dihydroxy-7-methoxy flavanone (*4*). The gum turpentine contains 75% *l*-β-pinene, 10% *l*-α-pinene, and 10% *l*-camphene (*6, 7*). For information on extractives see Drew and Pylant (*8*).

Pulping

Kraft. The wood is readily reduced to a strong pulp; yield is normal, and the pulp is easily bleached (*3, 9, 10*).

Sulfite. Sapwood is readily reduced, and the pulp has fair strength and good color; heartwood is difficult to pulp (*9, 11*).

Groundwood. See Schafer (*12*).

Soda. The wood is readily reduced, color is good, and the pulp is not so good as bleached hardwood soda pulps; the yield is normal (*3*).

Neutral Sulfite Semichemical. The pulp is somewhat brash, dark colored, and much weaker than kraft (*3*).

Literature Cited

1. Chang, Y. P. USDA Tech. Bull. No. 1095, 1954, 86 p.
2. Koch, P. Unpublished data from USDA Forest Serv. study FL-SO-3201-5.8.
3. Bray, M. W. and Martin, J. S. Southern Pulp Paper Jour. 5(1):7(19420.
4. Lindstedt, G. Acta Chem. Scand. 4:1042-6(1950).
5. Lindstedt, H. and Misiorny, A. Acta Chem. Scand. 5:121-8(1951).
6. Schorger, A. W. Ind. Eng. Chem. 7:321-2(1915).
7. Mirov, N. T. USDA Forest Serv. Tech. Bull. No. 1239. 1961.
8. Drew, J. and Pylant, G. D. Tappi 49(10): 430-438 (Oct., 1966).
9. Wells, S. D. and Rue, J. D. USDA, Dept. Bull. No. 1485, 1927, 101 p.
10. Martin, J. S. USDA, FPL Report No. 2248, 1962, 6 p.
11. McGovern, J. N. and Keller, E. L. USDA, FPL: Report No. 1429, 1943.
12. Schafer, E. R. USDA, FPL Report No. 2220. 1961.

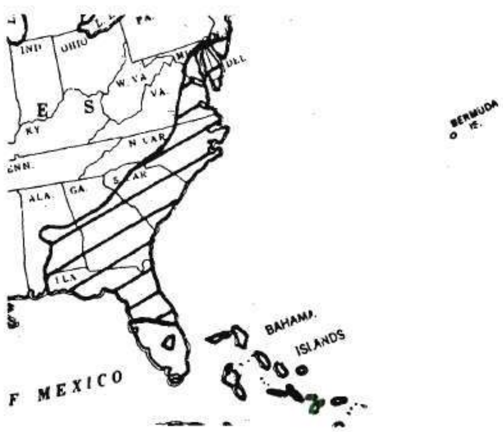
POND PINE

Scientific Name *Pinus serotina* Michx.

Synonyms Marsh pine, pocosin pine

Family Name Pinaceae

Range Atlantic and East Gulf coastal plain from southern New Jersey and Delaware to central Florida and southeastern Alabama.



Silvics In North Carolina pure stands are found in true upland bogs (pocosins) in interstream areas. Farther south, shallow, poorly drained depressions, called bays or ponds, frequently support stands of pond pine. Although pure stands most often grow on soils high in organic matter, the species develops best on mineral soils. This species also occurs in mixture with slash pine, loblolly pine, pond-cypress, redgum, sweetbay, loblolly-bay, redbay, and swamp tupelo. Pond pine is rated as intolerant.

Tree Dimensions A small to medium-sized tree, 40-50 feet (12-15 m) tall and 2 feet (61 cm) in diameter.

Pathology Resistance to decay: intermediate.

Pond pine is susceptible to southern fusiform rust (*Cronartium fusiforme*) and also to *C. quercuum*. Although the brown spot needle blight (*Scirrhia acicola*) causes a needle spot and dieback, the damage is usually not severe. The red heart rot (*Phellinus pini*) can reduce the value of the wood, particularly on poor sites.

The southern pine beetle (*Dendroctonus frontalis*) attacks pond pine, although it is not a favored species. Pond pine is also attacked by the engraver beetles (*Ips* spp.) and the black turpentine beetle (*D. terebrans*). Another pest is the pine sawfly (*Neodiprion excitans*), but pond pine is a less favored species than are loblolly and shortleaf pines.

Gross Features of the Wood Similar to loblolly pine.

Microscopic Structure of the Wood See the description for loblolly pine.

Tracheids. Average length, 3.0 mm.

Publications relating to wood ultrastructure and anatomical characteristics of stemwood include Cote and Day (*1*), Howard and Manwiller (*2*), Thomas (*3*) and Thomas and Nicholas (*4*). See the publication by Britt for fiber coarseness (*5*).

Gross Features of the Bark Grayish brown, very wide, irregular ridges or patches composed of many loose, irregular, friable scales.

Microscopic Structure of the Bark See the description for pitch pine.

Publications on bark structure include Howard (*6*), Martin (*7*) and Martin and Crist (*8*).

Physical Properties of Wood.

Specific gravity	Green volume	0.50
	Air-dry volume	0.54
	Oven-dry volume	0.58
Density, lb/cu ft (kg/cu m)	Green	49 (785)
	Air-dry	38 (609)
	Oven-dry	36 (577)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	31 (497)
Specific gravity, green volume, oven-dry weight (based on one tree) (*9*)	Earlywood 0.29	Latewood 0.64

According to Taras and Saucier (*10*), no geographic trends in specific gravity of pond pine were apparent within the range of the species.

Additional publications in this area include McElwee and Zobel (*11*) and Zobel, et al. (*12*).

Percent shrinkage, dried to 0% moisture content: r - 5.1, t - 7.1, v - 11.2.

Percent moisture content, when green

Green basis	36
Oven-dry basis	56

Chemical Composition of Wood

Proximate Analysis.

	Reiss & Libby (*13*)
Lignin, %	42.30
Holocellulose, %	54.76
Alpha-cellulose, %	45.70
Ash, %	0.26
Pentosans, %	11.30
Acetyl, %	3.62
Soluble in	
Cold water, %	2.60
Hot water, %	0.47
Alcohol-benzene, %	2.21
Ether, %	0.64
1% NaOH, %	10.53
10% KOH, %	19.52

Buchanan et al. (*14*) found the ether solubles to be 2.8%.

Extractives. For percent composition, see Drew and Pylant (*15*). For heartwood extractives soluble in ether or acetone, see Lindstedt and Misiorny (*16*).

Buchanan et al. (*14*) found the composition of ether extractives to be 40% resin acids, 18% free fatty acids, 28% fats, and 14% unsaponifiables. Tannin is absent (*17*).

Pulping.

Groundwood. The young, fast-growth wood is suitable for groundwood pulp. However, it causes more or less trouble in papermaking because the pitch content limits the proportion in which it can be used. For making light-colored unbleached pulp, the wood must be relatively free of heartwood.

Kraft. The wood is readily reduced, yield is normal, and pulp is strong. It makes high-grade wrapping, fiberboard, and book stock (*18*).

Sulfite. The wood is readily reduced; pulp is of a reddish-gray tone, and is probably somewhat pitchy. It is easily bleached. It is used for wrapping and printing papers. With slight modifications of the standard process, it can be made into fair pulp with a reasonable bleach consumption, provided young growth or material containing a comparatively small amount of heartwood is used. Heartwood is difficult to pulp (*18*).

Literature Cited

1. Cote, W. A. and Day, A. C. State Univ. of Forestry at Syracuse Univ. Tech. Publ. No. 95, 1969, 70 p.
2. Howard, E. T. and Manwiller, F. G. Wood Sci. 2(2):77-86(1969).
3. Thomas, R. J. Wood & Fiber 1(2):110-23(1969).
4. Thomas, R. J. and Nicholas, D. D. Tappi 52(11):2160-3(1969).
5. Britt, K. W. Tappi 48(1):7-11(1965).
6. Howard, E. T. Wood Sci. 3(3):134-48(1971).
7. Martin, R. E. Forest Prod. Jour. 19(8): 23-30 (1969).
8. Martin, R. E. and Crist, J. B. Wood & Fiber 2(3):269-79(1970).
9. Koch, P. Unpublished data from USDA Forest Serv. Study FS-SO-3201-5.8.
10. Taras, M. A. and Saucier, J. R. USDA, Forest Serv. Res. Pap. SE-65, 1970, 12 p.
11. McElwee, R. L. and Zobel, B. J. In Proc. Forest Genetics Workshop, 1963, Macon, GA, pp. 18-25.
12. Zobel, B. J., Kellison, R. C., Matthias, M. F. and Hatcher, A. V. North Carolina Agricultural Experiment Sta. Tech. Bull. No. 208, 1972, 56 p.

13. Reis, C. J. and Libby, C. E. Tappi 43(5): 489-99 (1960).

14. Buchanan, M. A., Sinnett, R. V. and Jappe, J. A. Tappi 42:578-83(1959).

15. Drew, J. and Pylant, G. D., Jr. Tappi 49(10):430-8(Oct., 1966).

16. Lindstedt, G. and Misiorny, A. Acta Chem. Scand. 5:131-8(1951).

17. Russell, A. J. Am. Leather Chemists Assoc. 38:144(1943).

18. Wells, S. D. and Rue, J. D. U.S. Dept. Agr., Dept. Bull. 1485. May, 1927. 101 p.

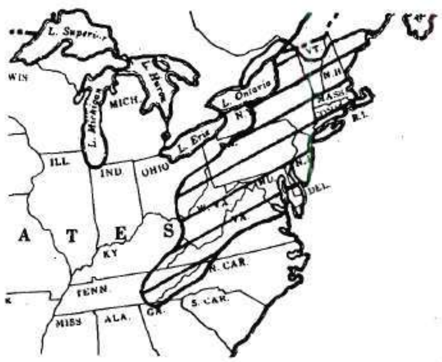
PITCH PINE

Scientific Name *Pinus rigida* Mill.

Synonyms Southern pine, southern yellow pine

Family Name Pinaceae

Range Northeast and the Appalachians; sea level to 3000 ft (910 m).



Silvics This species is quite variable in form and location. It will invade poor, sterile, sandy soils but grows best where moisture is adequate. It grows in fairly open, pure stands, or in mixture with such hardwoods as black, chestnut, and scarlet oaks, various hickories, red maple, and black tupelo. In New England it is commonly a small tree found on sandy soils with scrub oak and gray birch. The root system, at first deep, later becomes much shallower. Young trees commonly sprout from the root collar after destruction by fire or cutting. Good seed crops occur at three-year intervals. The species is rated as intolerant.

Tree Dimensions 50-60 ft (15-18 m) tall and 1-2 ft (30-61 cm) in diameter.

Pathology.

Although pitch pine is attacked by several fungi, none are serious. The heart rot, *Phellinus pini,* attacks pitch pine but generally is not important until the trees are about 75 years old (*1*). Rusts attacking pitch pine include several gall rusts (*Cronartium* spp.) and needle rusts (*Coleosporium* spp.).

The Nantucket pine tip moth (*Rhyacionia frustrana*) and the pitch pine tip moth, *R. rigidana,* feed on terminal and lateral needles and buds and attacks by the Nantucket tip moth are especially severe in young plantations. Pitch pine is also attacked by several sawflies, including the red-headed pine sawfly (*Neodiprion lecontei*), *N. pratti paradoxicus* and *N. pini rigidae.* Pitch pine is one of the favored species among the yellow pines for attack by the southern pine beetle (*Dendroctonus frontalis*). Loopers (*Lambdina* spp.) periodically cause considerable damage.

Gross Features of the Wood Mostly closely resembles shortleaf pine.

Microscopic Structure of the Wood See the description for loblolly pine.

Tracheids. Average length, 3.6 mm.

Publications on wood ultrastructure and anatomical characteristics of stemwood include Cote and Day (*2*) and Howard and Manwiller (*3*).

Gross Features of the Bark On young trees, dark in color, roughened and deeply furrowed; with age it becomes rather smooth and yellowish-brown to reddish-brown and breaks into large, irregular, flat plates with narrow seams and fissures.

Microscopic Structure of the Bark (*4*).

Bark characteristics of all southern hard pines generally overlap.

Rhytidome. Scale-like and composed of conspicuous periderms with both thin and thick-walled cells.

Sclerenchyma. Absent in the secondary phloem.

Sieve Cells. Aligned in radial rows, and often every 10 or more cells are interrupted by parenchyma cells. The sieve areas appear mainly on the radial surface of sieve cells. They are aligned in single vertical rows or occasionally in pairs.

Rays. Fusiform rays are common and contain horizontal resin canals with thin-walled epithelial cells, usually 3 to 4 in number, forming the inner border of the canal as shown on tangential section. Albuminous cells are conspicuous and present in almost every ray close to the cambial region.

Parenchyma. Aligned in more or less continuous tangential lines of single layered cells or occasionally 2-3 layers in a short radial multiple. Cells contain tanniferous substance and long styloid crystals with pointed ends.

Publications on bark structure include Howard (*5*), Martin (*6*) and Martin and Crist (*7*).

Physical Properties of Wood

Specific gravity	Green volume	0.45
	Air-dry volume	0.49
	Oven-dry volume	0.52
Density, lb/cu ft, (kg/cu m)	Green	50 (801)
	Air-dry	34 (545)
	Oven-dry	32 (513)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	28 (448)

According to Ledig, et al. (*9*), tracheid length and specific gravity increased from north to south along topoclines but were more closely correlated with climatic variables than with geographic location *per se.*

An additional publication on specific gravity in pitch pine is Saucier and Clark (*10*).

Percent shrinkage, dried to 0% moisture content: r - 4.0, t - 7.1, v - 10.9.

Percent moisture content, when green

Green basis	44
Oven-dry basis	79

Physical Properties of Bark.

Specific gravity, oven-dry weight & volume (*11*)	0.39

An annotated bibliography on pitch pine has been compiled by Little, *et al.* (*12*).

Chemical Composition of Wood

Proximate Analyses.

	Cole et al. (*13*) Corewood	Outerwood
Holocellulose, %	78.07	81.13
Alpha-cellulose, %	55.28	62.14

Extractives. For information on heartwood extractives soluble in ether or acetone see Lindstedt and Misiorny (*14*); for ether-soluble extractives see Rydholm (*15*); for other information on extractives see Erdtman (*16*). For percent composition of extractives see Drew and Pylant (*17*).

Pulping.

Kraft. The wood is readily reduced; it is strong, and the yield is normal; it is used for high-grade kraft wrapping paper, fiberboard, and book stock (*18*).

Sulfite. The wood is reduced with difficulty and is too pitchy for commercial production (*18*).

Utilization of Wood and Bark.

Use properties of wood. The wood makes good common lumber; naturally open-grown trees have many knots; the close-grown trees have wood which is straight grained, free from knots, and relatively free from resin.

Calorific Value of Wood. 6,790 kcal/kg.

Chemical uses of wood. The wood is used for production of tar and shoemaker's wax.

Other uses of wood. The wood is used for rough construction, door frames, interior finish, boxes and crates, furniture, water wheels, building timbers, fence rails, boats, bridge timbers, mine props, boxes and crates, flooring and interior finish, barrel headings, piling, fuel, vats for cold acids, charcoal.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 271, 1965. 762 p.
2. Cote, W. A. and Day, A. C. State Univ. of Forestry at Syracuse Univ. Tech. Pub. No. 95, 1969. 70 p.
3. Howard, E. T. and Manwiller, F. G. Wood Sci. 2(2): 77-86 (1969).
4. Chang, Y. P. Tappi Monograph Series No. 14, 1954. 249 p.

5. Howard, E. T. Wood Sci. 3(3):134-48(1971).

6. Martin, R. E. Forest Prod. Jour. 19(8): 23-30 (1969).

7. Martin, R. R. and Crist, J. B. Wood & Fiber 2(3): 269-79(1970).

8. Ifju, G. Wood Sci. 2:11-19(1969).

9. Ledig, F. T., Zobel, B. J. and Matthias, M. F. Can. Jour. For. Res. 5(2):318-29(1975).

10. Saucier, J. R. and Clark, A., III. USDA, Forest Serv. Res. Pap. SE-63, 1970. 16 p.

11. Harkin, J. M. and Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969. 42 p.

12. Little, S., McCormick, J. and Andresen, J. W. USDA, Forest Serv. Res. Pap. NE-164, 1970. 103 p.

13. Cole, D. E., Zobel, B. J. and Roberds, J. H. Proc. 3rd TAPPI Forest Biol. Conf. (Madison), Session 2, Paper 2, 1965. 26 p.

14. Lindstedt, G. and Misiorny, A. Acta Chem. Scand. 5:121-8(1951).

15. Rydholm, S. A. Pulping Processes, p. 224. New York: Interscience. 1965. 1269 p.

16. Erdtman, H. Progress in Organic Chemistry 1:22-63 (1952).

17. Drew, J. and Pylant, G. D., Jr. Tappi 49(10): 430-8(Oct., 1966).

18. Wells, S. D. and Rue, J. D. USDA, Dept. Bull. 1485. May, 1927. 101 p.

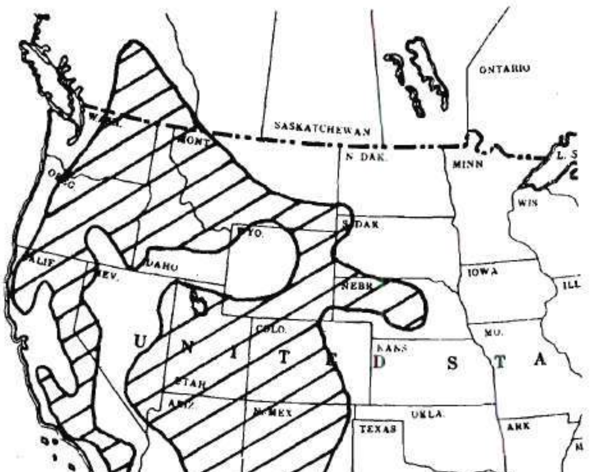
PONDEROSA PINE

Scientific Name *Pinus ponderosa* Dougl. ex Laws

Synonyms Western yellow pine, blackjack pine, bull pine, rock pine, pino real.

Family Name Pinaceae.

Range Western North America. The most widely distributed pine in North America, covering in excess of 43 million acres (17.4 million ha). Its range extends from British Columbia in the north to Mexico in the south and from Nebraska west to the Pacific Ocean. In the Pacific Northwest, it is found from sea level to 6000 ft (1830 m), in northern Idaho and central California from 2000-7000 ft (610-2130 m), and in Arizona from 4000-8000 ft (1220-2400 m) in elevation. However, the best developed stands are usually at elevations of 4000 to 8000 ft (1,200-2,400 m) on benches, plateaus and west and south aspects.



Silvics The tree has a long, symmetrical bole, clear for at least half its length, a short, conical, or flat-topped crown in old trees, and a taproot with a well-developed system of moderately deep, wide-spreading lateral roots. Although ponderosa pine is not exacting in its site requirements, it probably reaches its best development on well-drained, deep, sandy gravel and clay loams, as shown by its performance on such sites and its frequent absence where an impervious substratum exists. It occurs in many parts of its range in pure stands and is also commonly the most abundant tree in mixed conifer stands. In eastern Washington and Oregon its associates are western larch, Douglas-fir and, occasionally, lodgepole pine. In the central Rockies it occurs principally with Douglas-fir and in California with Jeffrey and sugar pines, white fir, incense-cedar and Douglas-fir. The species is intolerant.

Tree Dimensions Commonly, 90-130 ft (27-40 m) in height and 30-50 in (75-125 cm) in diameter (*2*). Best growth when tree numbers average 150-400 trees per acre (370-990 trees ha).

Pathology Resistance to decay: low+

Dwarf mistletoe (*Arceuthobium* sp.) causes more damage to ponderosa pine than any other disease. It attacks trees of all ages and develops best in vigorous trees. The root and butt rot, *Heterobasidion annosum* is one of the more insidious pathogens, attacking trees of all ages. Other diseases of ponderosa pine include *Elytroderma deformans,* a needle blight and several blister rusts. Paintbrush blister rust (*Cronartium filamentosum*), western gall rust (*C. coleosporioides*) and comandra rust (*Cronartium commandrae*) are all rusts which attack ponderosa pine.

The most destructive insects of ponderosa pine are several species of *Dendroctonus* (bark beetles). The mountain pine beetle (*Dendroctonus ponderosae*) infests mature stands and decimates large acreages, particularly in the central Rocky Mountain Region. The western pine beetle (*Dendroctonus brevicomis*) causes greatest losses in California, Oregon and Washington. Other important species of this genus include *D. convexifrons* and *D. valens.* The California flatheaded borer (*Melanophila californica*) generally attacks old or unhealthy trees but is capable of killing merchantable trees. Causing periodic damage are a number of defoliating insects, including the pine butterfly (*Neophasia menqpia*), the pandora moth (*Coloradia pandora*) and sawflies (*Neodiprion* spp.). The Arizona five-spined Ips (*Ips lecontei*) is one of the most destructive pine bark beetles on ponderosa pine in Arizona. However, more than five other species of Ips also attack ponderosa pine.

Gross Features of the Wood The sapwood is white to pale yellowish, and the heartwood is yellowish to light red brown to orange brown. The wood is moderately soft, generally straight and quite even to very uneven grained, medium coarse-textured, resinous, without characteristic taste but with a distinct, noncharacteristic resinous odor. The relationship between latewood and earlywood zones is variable; in slow, even growth, the latewood zone is very narrow, but in fast-growing young stock it is broad and conspicuous. This causes variation in appearance of the grain. The ring is always distinct and the transition from earlywood to latewood is abrupt. In the x-section the rays are very fine and are not distinct with the unaided eye unless they include a horizontal resin canal; in the r-section they form a fine, close, inconspicuous fleck. Both longitudinal and horizontal resin canals are normally present. The numerous longitudinal canals are conspicuous, confined largely to the central and outer portions of the ring, solitary or rarely 2-3 contiguous tangentially and appear as relatively prominent dark streaks along the grain. The horizontal canals are whitish, relatively inconspicuous wood rays spaced irregularly on the x-section, and barely visible with a hand lens as brown specks on the t-section. Longitudinal parenchyma cells are absent. The split tangential surface is frequently dimpled but the dimples are less conspicuous than in lodgepole pine. Additional information in this area is Howe (*3*).

Microscopic Structure of the Wood.

Tracheids. Average 3.6 mm in length and 35-45 μm in diameter. (Cell wall thickness average 3.38 μm.) Coarseness 26 mg/100 m. Bordered pits in one row (occasionally in two) on the radial walls; tangential pitting may be present on the last few rows of latewood tracheids; pits leading to ray parenchyma variable in shape and size (pinoid), 1-7 (generally 4 or 5) per cross-field. Volume occupied, approximately 93%.

Resin Canals. Longitudinal, average, 160-185 μm in diameter; horizontal, less than 70 μm; thin-walled epithelial cells, tylosoids present in the heartwood. Volume occupied, <1%.

Rays. Two types, uniseriate and fusiform; the uniseriate rays are numerous, 1-12+ cells high; the fusiform rays are scattered, with a horizontal resin canal, 3- to 5-seriate in the central portion, tapering to uniseriate margins, up to 20+ cells in height; ray tracheids present in both types of rays, marginal (often in several rows) and occasionally interspersed, with prominently dentate inner walls. Low rays frequently consist entirely of ray tradheids. Volume occupied, approximately 7%.

Longitudinal Parenchyma. Absent.

Gross Features of the Bark Bark of the young ponderosa pine is deeply furrowed and brown to black, but as the tree grows older, it becomes yellowish-brown to cinnamon colored and breaks into large, flat, superficially scaly plates separated by deep, irregular fissures on slow-growing and old trunks; very thick on old trees. Scales are large, and the main portion of the rhytidome lines are parallel to one another. On cross section, the yellowish periderm is in sharp contrast to the reddish-brown secondary phloem. Additional information in this area is Chang (*4*).

Microscopic Structure of the Bark

Rhytidome. In mature bark, it consists of alternating layers of old periderm and dead phloem. The periderms are rather broad and composed of a layer of phellogen, several layers of expanded parenchymatous cells or phelloderm and a number of thin-walled phellem cells that usually alternate with thick-walled cells. Remnants of the phloem lie to the outside of each periderm, and the expanded parenchyma cells or phelloderm occupy much of the area between periderms.

Secondary Phloem. Composed of sieve cells, phloem parenchyma and phloem rays. Sieve cells are aligned in radial rows, often four to six cells, sometimes up to ten cells in a continuous row, interrupted by more or less single tangential lines or sometimes sporadically arranged parenchyma cells. These two types of cells are bordered radially by uniseriate and fusiform rays.

Sieve Cells. Average 3.0-4.0 mm in length with a width of 35-40 μm tangentially and 25-30 μm radially (whole, unmacerated cells near the cambium zone).

Sclerenchyma. Absent in the inner bark.

Parenchyma. The cross sections of the phloem parenchyma cells in the proximity of the cambium zone are similar to the cross sectional area of the sieve cells in this region. The parenchyma cells become expanded and are oval to circular in cross sectional area after a few seasons of growth. The average diameter of these cells is between 40-50 μm. The average longitudinal length of individual parenchyma cells is between 75-100 μm.

Rays. Phloem rays attain a height of 8-10 cells (300 μm). Horizontal resin canals are present in the fusiform rays.

Physical Properties of Wood

Specific gravity	Green volume	0.39
	Air-dry volume	0.40
	Oven-dry volume	0.42

Density, lb/cu ft (kg/cu m)	Green	45 (721)
	Air-dry	28 (448)
	Oven-dry	26 (416)

Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	24 (384)

Overall decrease in specific gravity with increase in height of tree (*5*).

Specific gravity decreased with increasing height and increased with age and with increasing latewood percent in the annual rings, with latewood percent being the best predictor of specific gravity (*6*).

Specific gravity decreased as the altitude of origin of the seed parents increased (*7*).
Percent shrinkage, (*8*),
dried to 20% moisture content: r - 1.3, t - 2.1, v - 3.2
dried to 6% moisture content: r - 3.1, t - 5.0, v - 7.7
dried to 0% moisture content: r - 3.9, t - 6.3, v - 9.6

Percent moisture content, when green

Green basis	48
Oven-dry basis	91

Percent moisture content (*8*) oven-dry basis

Heartwood	40
Sapwood	148

Additional information in this area includes Barger and Ffolliott (*9*), Cockrell and Howard (*10*), Conway and Minor (*11*), Echols (*12*), Markstrom and Yerkes (*13*), Voorhies and Jameson (*14*), Voorhies (*15*), and Paul (*16*).

Physical Properties of Bark

Specific gravity, green volume	Inner bark	0.34
	Outer bark	0.35
	Total bark	0.35

Density (100% moisture content)	Green weight/ green volume	0.62

Percent moisture content, oven-dry basis (*17*)	Inner	78
	Outer	21

Three general bibliographies on ponderosa pine have been compiled by Axelton (*18, 19, 20*).

Chemical Composition of Wood.

	Corder (*21*)
Volatile matter, %	87.0
Fixed carbon, %	12.8

	F.P.L.	Anderson (*22*) Sap	Anderson (*22*) Heart	Wise (*23*)
Lignin, %	26.7	22.8	22.9	24.4
Holocellulose, %	–	69.9	66.3	–
C. & B. cellulose, %	57.4	59.9	58.1	–
Alpha-cellulose, %	37.4	–	–	–
Hemicellulose A, % (extd. with 5% KOH)	–	–	–	10.0
Hemicellulose B, % extd. with 24% KOH)	–	–	–	2.95
Ash, %	0.46	0.3	0.2	0.19
Pentosan				
Total	7.35	10.5	10.4	–
In cellulose, %	6.82	–	–	–
Mannan, %	4.64	–	–	7.20
Acetyl, %	1.09	–	–	0.68
Methoxyl, %	4.49	–	–	–
Xylan, % (cor. for uronic anhydride)	–	–	–	8.60
CH_2, % (from MeO not in lignin)	–	–	–	0.23
Solubility in				
Alcohol-benzene, %	4.4	5.1	7.2	
Ether, %	8.52	4.8	5.0	
1% NaOH, %	20.3	–	–	
Cold water, %	4.09	1.0	3.3	
Hot water, %	5.05	4.3	6.2	

Carbohydrates.

	Smith and Zavarin (*24*) Heart	Smith and Zavarin (*24*) Sap
Free carbohydrates, dry weight basis		
Glucose, %	tr.	0.04

Fructose, %	–	0.04
Sucrose, %	–	0.04
Raffinose, %	–	0.02
Arabinose, %	0.3	–
Stachyose, %	–	tr.
Unidentified, %	–	tr.

Extractives.

	Anderson, et al. (*25*)	
	Heart	Sap
Ether-soluble extract, %	28.2	3.5
Neutrals, %	42.0	65.0
Acids, %	58.0	35.0
Fatty acids, %	3.0	44.0
Resin acids, %	97.0	50.0
Unidentified acids, %	–	6.0
Total acids in wood, %	16.4	1.2

	Rogers, et al. (*26*)
Acetone soluble, %	3.89
Diethyl ether insoluble, %	0.90
Diethyl ether soluble, %	2.96
Petroleum ether insoluble, %	0.26
Petroleum ether soluble, %	2.70
Moisture content of wood, %	52.3

Tannin content is 8.9% (*27*).

Other references dealing with chemical composition of wood include Dore (*28*), Anderson (*29*), Drew and Pylant (*30*), Riffer and Anderson (*31*), Anderson, *et al.* (*25*), Erdtman (*32*), Smith, *et al.* (*33*) and Anderson (*34*).

Chemical Composition of Bark

Carbohydrates.

	Smith and Zavarin (*24*)	
Free carbohydrates, dry weight basis	Outer bark	Inner bark
Glucose, %	0.3	1.5
Fructose, %	–	1.8
Sucrose, %	–	1.5
Raffinose, %	–	0.1
Arabinose, %	0.02	–

	Corder (*21*)
Volatile matter, %	73.4
Fixed carbon, %	25.9

	Institute Paper Chemistry Project 3212, Report 5 (*32*)
Alcohol-benzene extractives, %	15.7
Silica, %	0.16
Calcium, %	0.2
Ash, %	0.7

For information on elements in bark, see Harder & Einspahr (*35*).

Pulping.

Kraft. The wood is readily reduced; the pulp has average strength; it is used for high-grade wrapping papers and fiberboard, printing papers, and duplicating papers. Yield for wood is 47% (Kappa No. 31.8); wood plus bark, 41% (Kappa No. 32.2).

The pulp is similar to jack pine pulp except for lower chemical requirements and lower yields of screen rejects; the pulp strength is similar to that of jack pine pulp (*36*).

Mechanical. The wood is fairly readily reduced, and it has satisfactory color and soft texture; it requires more power than white spruce; it is pitchy. For making light-colored unbleached groundwood pulp, the wood must be relatively free of heartwood. Groundwood is used for hardboard. Groundwood can be bleached in a two-stage process with hypochlorite and peroxide.

Groundwood pulps from thinnings and tops were equal in strength and higher in brightness than the average of a number of commercial newsprint-grade groundwood pulps. Chip groundwood had about the same burst and tensile strength as ordinary groundwood pulp of the same freeness, and it has a higher tear resistance and larger proportions of the longer fibered fractions. Groundwood and chip groundwood pulp can be used with chemical pulp for good quality book paper, newsprint, toweling, art paper, and pulp board (*37*).

Sulfite. Sapwood is reduced fairly readily and heartwood is reduced with difficulty; the yield is normal, color is dark, and the pulp is shivy.

Additional Information. See articles by Hatch and Holzer (*38*), Thickens, J. H. and McNaughton (*39*), Wells and Rue (*40*), Horn and Auchter (*41*), and Smedberg and Stalter (*42*).

Utilization of Wood and Bark.

Use Properties of Wood. Soft-textured, delicately figured, straight, close, and uniform grained, nails easily without splitting but has low nail-holding power, easy to work, low shrinkage, stays in place well, subject to blue stain, takes and holds paint well, glues easily, slightly resinous, easily treated with preservatives. It is satisfactory for pulpwood.

Calorific Value of Wood.

Calorific value of air-dry cord – 5.57×10^6 kcal
– 22.1×10^6 Btu

kcal/oven-dry kg – 5,067
Btu/oven-dry lb – 9,120

Calorific Value of Bark.

Btu/oven-dry lb – 9,616
kcal/oven-dry kg – 5,343
Btu/ft^3 – 209,600
kcal/m^3 – 1,494

Chemical Uses of Wood. Alcohol production: 52 gallons of 95% alcohol per ton by the Madison Process.

Other Uses of Wood. Building construction, boxes, furniture, windows, panel doors, patterns, toys, caskets, luggage, posts, poles, pulpwood, fuel, particle boards, structural insulation board, decorative boards, and acoustical tiles.

Other Uses of Bark. Bark extract is used as a bonding agent for particle board and bark is used for boards.

Literature Cited

1. Kotok, E. S. USDA, Forest Serv. Publ. No. FL-254, 1973.
2. USDA, Forest Serv. Agriculture Handbook No. 271, 1965.
3. Howe, J. P. The influence of irrigation on wood formation in ponderosa pine. Ph.D. Thesis. Univ. of Michigan, 1966.
4. Chang, Y. P. USDA, Tech. Bull. No. 1095, 1954.
5. Okkonen, E. A., Wahlgren, H. E. and Maeglin, R. R. Forest Prod. Jour. 22(7):37-42(1972).
6. Voorhies, G. Arizona For. Notes, North. Ariz. Univ. No. 7, 1972, 16 p.
7. Echols, R. M. and Conkle, M. T. For. Sci. 17(3): 388-94(1971).
8. U.S. Forest Products Lab. Agriculture Handbook No. 72, 1974.
9. Barger, R. L. and Ffolliott, P. F. USDA, Forest Serv. Res. Note RM-205, 1971.
10. Cockrell, R. A. and Howard, R. A. Wood Sci. and Technology 2:292-298(1968).
11. Conway, E. M. and Minor, C. O. Rocky Mountain Forest & Range Expt. Sta. Research Note No. 54, 1961.
12. Echols, R. M. Proc. Conf. Growth Acceleration Effect on Wood Properties, Nov., 1971, Madison, WI, H1-18.
13. Markstrom, D. C. and Yerkes, V. P. USDA, Forest Serv. Res. Note RM-213, 1972.
14. Voorhies, G. and Jameson, D. A. Forest Prod. Jour. 19(5):52-5(1969).
15. Voorhies, G. Forest Prod. Jour. 19(6):45-6(1969).
16. Paul, B. H. Forest Prod. Jour. 7(11):408-10(1957).
17. Smith, J. H. G. and Kozak, A. Forest Prod. Jour. 21(2):38-40(1971).
18. Axelton, E. A. USDA, For. Serv. Res. Pap. INT-40, 1967.
19. Axelton, E. A. USDA, For. Serv. Gen. Tech. Rep. INT-12, 1974.
20. Axelton, E. A. USDA, For. Serv. Gen. Tech. Rep. INT-33, 1977.
21. Corder, S. E. 1973. Oregon State Univ., Forest Research Laboratory, Corvallis. Research Bulletin 14.
22. Anderson, A. B. Ind. Eng. Chem. 36:662(1944).

23. Wise, L. E., Murphy, M. and D'Addieco, A. A. Tech. Assoc. Papers 29:210 (1946); Paper Trade J. 122(2):35(Jan. 10, 1946).

24. Smith, L. V. and Zavarin, E. Tappi 43(3):218-221(March, 1960).

25. Anderson, A. B., Riffer, R. and Wong, A. Phytochem. 8(5):873-875(May, 1969).

26. Rogers, I. H., Jarris, A. G. and Rozon, L. R. Can. Dept. Forestry Inform. Rept. VP-X-57: 29 p. (Dec., 1969).

27. Bensen, H. K. and Jones, F. M. J. Ind. Eng. Chem. 9:1096(1917).

28. Dore, W. H. J. Ind. Eng. Chem. 12:476(1920).

29. Anderson, A. B. Ind. Eng. Chem. 38:450(1946).

30. Drew, J. and Pylant, G. D., Jr. Tappi 49(10): 430-8(Oct., 1966).

31. Riffer, R. and Anderson, A. B. Holzforsch. 20(1): 36-8(Feb., 1966).

32. Erdtman, H. Progress in Organic Chemistry 1:22-63 (1952).

33. Smith, R. H., Peloquin, R. L. and Passof, P. C. U.S. Forest Serv., Res. Paper PSW-56: 10 p. (1970).

34. Anderson, A. B. J. Inst. Wood Sci.(10):29-47 (Nov., 1962).

35. Harder, M. L. and Einspahr, D. W. To be submitted to Tappi.

36. Martin, J. S. U.S. Dept. Agr., Forest Service, Forest Products Laboratory Report 1909, 3 p. (Oct., 1951).

37. Schafer, E. R. and Hyttinen, A. U.S. Dept. Agr., Forest Service, Forest Products Laboratory Report R1947, 13 p. (Revised Sept., 1959).

38. Hatch, R. S. and Holzer, W. F. TAPPI Monograph No. 4:153(1947).

39. Thickens, J. H. and McNaughton, G. C. U.S. Dept. Agr., Bull. 343. 1916.

40. Wells, S. D. and Rue, J. D. U.S. Dept. Agr., Dept. Bull. 1485. May, 1927. 101 p.

41. Horn, R. A. and Auchter, R. J. Paper Trade J. 156(46): 55-59(Nov. 6, 1972).

42. Smedberg, G. E. and Stalter, N. J. Paper Trade J. 141(51):20-5(Dec. 23, 1957).

JEFFREY PINE

Scientific Name *Pinus jeffreyi* Grev. & Balf.

Synonyms Western yellow pine, bull pine, black pine, ponderosa pine.

Family Name Pinaceae

Range Southern Oregon to Lower California. Up to 3500 ft (1070 m) elevation in the north and 10,000 ft (3050 m) in the south.

Silvics The habits of Jeffrey pine are quite similar to those of ponderosa pine. The tree is found in mixture with ponderosa pine and its associates or in small, pure stands. It can endure greater extremes in climate, however, and hence is more important on the eastern slopes of the Sierra Nevada than is ponderosa pine. The species is rated as intolerant.

Tree Dimensions 90-100 ft (27-30 m) tall and 3-5 ft (91-152 cm) in diameter.

Pathology

Few needle diseases are of any importance, with tarweed rust, *Coleosporium madiae* the only needle rust on the species. Jeffrey pine is also a host for *Peridermium filamentosum, P. harknessii, P. stalactiforme, Cronartium comandrae* and *C. comptoniae*. The most serious disease of Jeffrey pine is dwarfmistletoe (*Arceuthobium campylopodum*), and it occurs mainly from southern Oregon to Baja California. The root rot, *Heterobasidion annosum*, is also of economic importance.

Sawflies (*Neodiprion* spp.) are an occasional problem. The Jeffrey pine beetle (*Dendroctonus jeffreyi*) is the most destructive bark beetle, attacking individual mature and overmature trees. The Ips beetle (*Ips emarginatus*) is frequently found in association with the Jeffrey pine beetle. The California flatheaded borer (*Melanophila californica* Van Dyke) also attacks Jeffrey pine, preferring old or unhealthy trees.

Gross Features of the Wood Similar to ponderosa pine. Heartwood sometimes has a pinkish cast. Wood has a sweet odor when freshly cut.

Microscopic Structure of the Wood

See the description for ponderosa pine.

Gross Features of the Bark Similar to that of ponderosa pine but darker cinnamon red and commonly tinged with lavender or purple on old trunks. The periderm is yellowish, while the secondary phloem is reddish-brown (*1*).

Microscopic Structure of the Bark (*1*)

Rhytidome. Scalelike, with conspicuous periderm composed of both thin- and thick-walled cells.

Sclerenchyma. Absent in the secondary phloem.

Sieve Cells. Often in radial rows of about 10 cells.

Rays. Fusiform rays common.

Parenchyma. Often 1 to 3 parenchyma cells in a short radial multiple, forming rather irregular tangential lines on cross section of the inner bark, and containing crystals with rectangular lateral faces.

Nonmechanical Physical Properties of Wood

Specific gravity	Green volume	0.37
	Air-dry volume	0.40
	Oven-dry volume	0.41
Density, lb/cu ft (kg/cu m)	Green	47 (753)
	Air-dry	28 (448)
	Oven-dry	26 (416)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	23 (368)

Percent shrinkage, dried to 0% moisture content: r - 4.4, t - 6.7, v - 9.9

Percent moisture content, when green

Green basis	50
Oven-dry basis	101

Chemical Composition of Wood

Extractives. Schorger (*2*) reported 95% heptane and 5% of an aldehyde, apparently citronellal, in the gum turpentine. Foote (*3*) identified *n*-octyl, *n*-nonyl, and *n*-decyl aldehydes. Smith (*4*) reported 94.7% heptane, 1.1% nonane, 0.4% α-pinene, 0.5% undecane, 0.2% β-pinene, 1.4% Δ^3-carene, 0.9% myrcene, and 0.8% β-phellandrene in the wood oleoresin. Anderson, et al. (*5*) found 2.8% ether-soluble extractives in the sapwood and 10.5% in the heartwood, with 1.8% and 7.2%, respectively, as total acids. The principal difference between Jeffrey pine and ponderosa pine was the presence of *n*-heptane, *n*-nonane, and *n*-undecane in the steam-volatile fraction of Jeffrey pine only. Heartwood contains pinosylvin monomethyl ether, pinosylvin, pinocembrin, pinobanksin, and L-arabinose (*6, 7*). The heartwood of well-seasoned stumps contains about 26% benzene-soluble extractive material, over one-half of which consists of resin acids, largely of the two double bond abietic acid type (*8*). A water-soluble polysaccharide consisting of L-arabinose and D-galactose was isolated from the heartwood (*9*). The yield was 1.5% based on benzene extracted o.d. wood.

Pulping

The wood is expected to behave much like ponderosa pine.

Utilization of Wood and Bark

It is customary to log Jeffrey and ponderosa pines together and, because of the great similarity of their timbers, no attempt is made to segregate them in the trade.

Literature Cited

1. Chang, Y. P. USDA Tech. Bull. No. 1095, 1954. 86 p.
2. Schorger, A. W. J. Ind. Eng. Chem. 5:971-3 (1913).
3. Foote, P. A. Amer. Pharm. Assoc. Jour. 28:350-3 (1929).
4. Smith, R. H. Forest Sci. 13(3):246-52(1967).
5. Anderson, A. B. Paper Trade Jour. 129(2):35-7 (1949).
6. Lindstedt, G. Acta Chem. Scand. 3:770-2(1949).
7. Lindstedt, G. and Misiorny, A. Acta Chem. Scand. 5:121-8 (1951).
8. Anderson, A. B. Tappi 37(7):316-20(1954).
9. Wadman, W. H., Anderson, A. B. and Hassid, W. Z. Jour. Am. Chem. Soc. 76:4097-4101(1954).

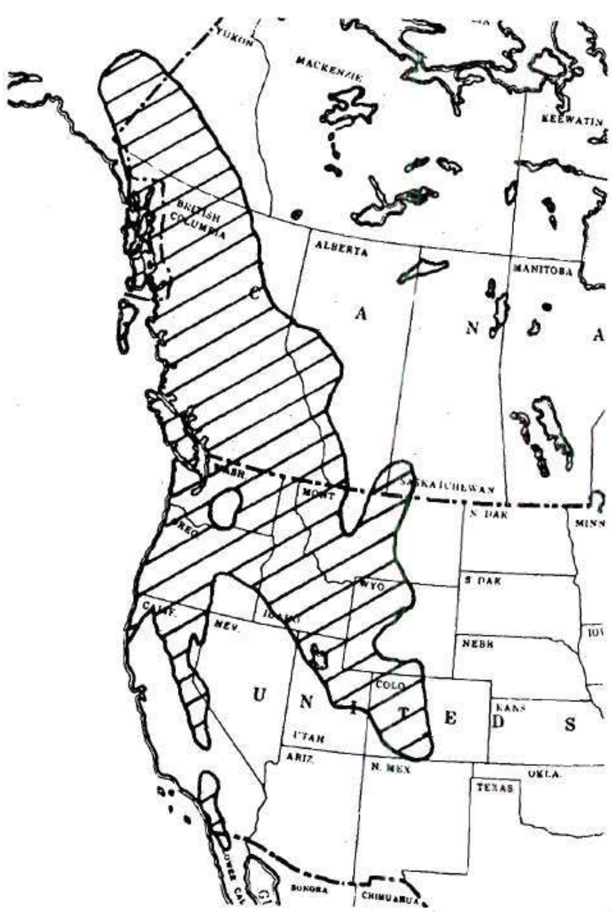
LODGEPOLE PINE

Scientific Name *Pinus contorta* Dougl.

Synonyms Black pine, scrub pine, tamarack pine, shore pine, coast pine.

Family Name Pinaceae.

Range Western North America, covering 14.8 million acres (6 million ha) on a wide variety of sites, principally in the Rocky Mountains. Its range extends from Alaska and the interior Yukon territory south to northern Baja California and east to the Black Hills of South Dakota. The species grows from latitude 64°N to 31°N (*1*). Elevations are from sea level to 2000 ft (610 m) in the north, to 6000 ft (1830 m) in the Pacific Northwest, to 11,500 ft (3500 m) in California and 6000-11,000 ft (1830-3350 m) in the Rockies.



Silvics Separate taxonomic recognition of four groups of lodgepole pine have been proposed (*2*). They are: Coastal group (*Pinus contorta* Douglas ex Loudon ssp. *contorta*), Mendocino white plains group (*Pinus contorta* ssp. *bolanderi* [Parl.] stat. nov.), Sierra Nevada group (*Pinus contorta* ssp. *murrayana* [Balf.] stat. nov.), and the Rocky Mountain group (*Pinus contorta* ssp. *latifolia* [Engelmann ex Watson] stat. nov.). However, others contend that, because of the nature of the differences between the groups and their inconstancy, separate taxonomic recognition should not be made. Because of its small size and poorly formed bole, the coastal (shore) pine contributes little to the timber supply. In the mountains the medium-sized tree has a long, clear, slender, cylindrical bole, a short, narrow, open crown and a shallow root system. The trees reach commercial size on many soil types but attain their best development on a moist, well-drained sandy or gravelly loam. This species is very aggressive and hardy. Thus, in many areas, it is found in pure, dense, even-aged stands but also occurs in mixture with other conifers. At lower elevations its associates are ponderosa and western white pines, Douglas-fir and western larch. At higher altitudes, it occurs chiefly with Engelmann spruce, subalpine fir and limber pine in the Rockies and limber and Jeffrey pines and California red fir in the Sierra Nevada. In pure, dense stands the trees are prone to stagnation. The species is intolerant.

Tree Dimensions Mountain form – 60-80 ft (18-24 m) tall and 7-13 in (18-33 cm) in diameter at 140 years of age in the main lodgepole region (*3*). Coastal form – 25-30 ft (7.6-9.1 m) tall and 12-18 in (30-46 cm) in diameter.

Pathology Resistance to decay: low+.

Dwarf mistletoe (*Arceuthobium americanum*) and comandra rust (*Cronartium comandrae*) are the two most destructive diseases infecting lodgepole pine. Dwarf mistletoe, which is widespread, reduces growth significantly and sometimes kills trees. Comandra rust is less widespread but kills more trees. Other diseases of lodgepole pine include western gall rust (*Peridermium harknessii*), *P. stalactiforme* and the heartrot fungi, *Phellinus pini* and *Stereum pini*.

The most destructive insect pest of lodgepole pine is the mountain pine beetle (*Dendroctonus ponderosae*). It infests mature forests, and epidemics have wiped out thousands of acres. The lodgepole pine beetle (*Dendroc-

tonus murrayanae) is less aggressive, mining in the base of overmature, weakened and injured trees. The principal defoliating insects are the lodgepole needle miner (*Coleotechnites milleri*), the lodgepole sawfly (*Neodiprion burkei*) and the spruce budworm (*Choristoneura fumiferana*).

Gross Features of the Wood The wood of lodgepole pine is moderately soft, generally straight but somewhat uneven grained, medium fine-textured, resinous, without characteristic taste, but with a distinct noncharacteristic, resinous odor (especially when green). The sapwood is nearly white to pale yellow and narrow. The heartwood is light yellow to pale yellow brown, often scarcely darker than the sapwood and not clearly distinct. The springwood zone is usually much wider than the narrow, distinct summerwood zone except in the outer rings of mature trees. The transition from springwood to summerwood is more or less abrupt. In the x-section the rays are very fine and are not distinct with the naked eye even when they enclose a horizontal resin canal; in the r-section they form a fine, close, inconspicuous fleck. Both longitudinal and horizontal resin canals are normally present. The longitudinal canals, which are relatively inconspicuous or not visible with the naked eye, are numerous, confined largely to the central and outer portions of the ring, solitary for the most part, and forming fairly conspicuous, brownish streaks along the grain. The smaller horizontal canals, which appear as brown radial lines spaced irregularly on the transverse surface, are barely visible with a hand lens on the tangential surface. Parenchyma cells are absent. A split tangential section shows prominent dimpling effect. Additional information in this area includes Black (*4*).

Microscopic Structure of the Wood

Tracheids. Average 3.1 mm in length and 35-45 μm in diameter. Cell wall thickness average 3.02 μm. Weight factor (unbleached kraft) of 0.80 and coarseness of 23 mg/100 m. Bordered pits on one row or occasionally paired on the radial walls; tangential pitting absent; pits leading to ray parenchyma variable in size and shape (pinoid), 1-6 (generally 2-4) per ray crossing; ray tracheid pits present.

Resin Canals. Longitudinal, average, 80 to 90 μm in diameter; horizontal, less than 50 μm; thin-walled epithelial cells, tylosoids are in the heartwood. Lengths ranged from 3.8-43.2 cm in 75-year-old tree and 1.2-12.0 cm in a 30-year-old tree (*5*).

Rays. Two types, uniseriate, or part biseriate, and fusiform; the uniseriate rays are numerous 1-15+ cells in height; biseriate rays frequent in the areas of whirled tissue; the fusiform rays are scattered, with a horizontal resin canal, 2 to 3-seriate in the central portion, tapering to uniseriate margins, up to 15+ cells high; ray tracheids are present in all types of rays, marginal and interspersed, with prominently dentate walls. The marginal tracheids are often in several rows and in low rays the ray tracheids frequently compose the entire ray. Volume occupied, approximately 6%.

Longitudinal Parenchyma. Absent.

Gross Features of the Bark Lodgepole pine grown in the coastal region has thick bark, up to 1 inch, deeply furrowed and transversely fissured, and reddish-brown in color. The inland or mountain form has thinner bark, usually about 0.2 in (0.6 cm) thick, which is scaly and yellowish-brown in color. The outer bark usually shows narrow rhytidome layers with thin periderms contrasting with a narrow inner bark of finer texture and lighter-colored secondary phloem. The thin bark makes lodgepole pine highly susceptible to fire kill. Average bark thickness for 22 lodgepole pine trees in the Pacific Northwest – Inner-0.08 in (0.2 cm) and Outer-0.19 in (0.5 cm) (*6*).

Microscopic Structure of the Bark

Young Trees. Bark structure is quite similar to jack pine. The periderm is composed mainly of thin-walled phellem cells with a few alternating layers of thick and thin-walled phellem cells developing within five years. The cortical region is broad with large resin canals, and the secondary phloem has the basic pattern of parenchyma, sieve cells, and narrow rays.

Mature Trees.

Periderm. Formed rather close to the cambial region, consisting of a layer of phellogen, 2-3 layers of phelloderm and 5-10 layers of phellem. Peridermal cells are rectangular in shape on cross and radial sections, 30-50 μm in tangential diameter, and 20-30 μm in radial diameter on cross section. Phelloderm cells are parenchymatous in nature and often contain "resinous" substances and small crystals. Percent of total bark, approximately 18%.

Secondary Phloem. Narrow. All tissues become much expanded or deformed in the transformation to the outer bark. Percent of total bark, approximately 82%.

Sclerenchyma. Absent in the inner bark.

Sieve Cells. Rectangular on cross section, usually 2.2-4.4 mm in length (*7*). Percent of secondary phloem, approximately 78%.

Parenchyma. Sporadically distributed in discontinuous lines and interrupt the radial alignment of every 5-10 sieve cells. Individual parenchyma cells are about 100-250 μm in height and contain styloid crystals about 50 μm long. Parenchyma strands are about the same length as the adjacent sieve cell. Percent of secondary phloem, approximately 15%.

Rays. Albuminous or erect ray cells, 2-3 times the height of ordinary ray cells, are present and conspicuous in almost every ray close to the cambium. Uniseriate rays are usually 6-10 cells or 200-300 μm high on tangential section. Rays often become dilated at the outer bark, especially fusiform rays which contain resin canals, sometimes 2-3 in the same ray. Canals, formed by 3-4 thin-walled epithelial cells at the inner border, often enlarge to a diameter of 1.5 mm. Percent of secondary phloem, approximately 7%.

Physical Properties of Wood

Specific gravity	Green volume	0.38
	Air-dry volume	0.41
	Oven-dry volume	0.43
Density, lb/cu ft (kg/cu m)	Green	39 (625)
	Air-dry	29 (464)
	Oven-dry	27 (432)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	24 (384)

Percent shrinkage, (*8*)
dried to 20% moisture content: r - 1.5, t - 2.2, v - 3.8
dried to 6% moisture content: r - 3.6, t - 5.4, v - 9.2
dried to 0% moisture content: r - 4.5, t - 6.7, v - 11.5

Percent moisture content, when green

Green basis	39
Oven-dry basis	65

Percent moisture content, oven-dry weight (*8*)

Heartwood	41
Sapwood	120

In 100-year-old lodgepole pine, specific gravity decreased and moisture content increased with increasing height of the tree. Moisture content decreased and specific gravity increased with increasing mean age of the sample disk (*9*).

Additional information in this area includes Henderson and Petty (*10*) and Johnstone (*11*).

Physical Properties of Bark

Specific Gravity, green volume	Inner bark	0.32
	Outer bark	0.45
	Total bark	0.38
Density (100% moisture content)	Green weight/ green volume	0.74-0.95

Moisture Content, % oven-dry (*6*)

Inner	128
Outer	42

Chemical Composition of Wood

Proximate analyses.

	Fengel & Grosser (*12*)	Kurth (*13*)	F.P.L.
Lignin, %	25.0	28.39	
Holocellulose, %	63.2	72.10	–
C. & B. cellulose, %	–	–	58.7
Alpha-cellulose, %	–	–	45.7
Ash, %	0.2	0.36	–
Pentosan			
Total, %	9.2	15.60	12.4
In cellulose, %	8.8	–	–
Mannan, %	–	–	5.10
Acetyl, %	–	1.51	–
Methoxyl groups, %	–	4.36	–
Cellulose, %	43.8	–	–

Extractives.

	Institute Paper Chemistry Project 3212, Report 5	Kurth (*13*)	Anderson et al. (*14*)		Fengel & Grosser (*12*)
			Sap	Heart	
Alcohol-benzene sol., %	3.5	–	–		–
Alcohol sol., %	–	1.62	–	–	–
Hot water sol., %	–	1.80	–	–	3.6
Ether sol., %	–	1.56	3.9	3.6	2.3
Neutrals, %	–	–	45.0	38.0	–
Acids, %	–	–	55.0	62.0	–
Fatty acids, %	–	–	16.0	30.0	–
Resin acids, %	–	–	68.0	64.0	–
Unidentified acids, %	–	–	16.0	6.0	–
Total acids in wood, %	–	–	2.1	2.2	–

	Rogers, et al. (*15*)
Acetone sol., %	4.93
Diethyl ether insol., %	0.532
Diethyl ether sol., %	4.311
Pet. ether insol., %	1.272
Pet. ether sol., %	3.039
Moisture content of wood, %	39.26

For information on petroleum ether- and acetone-soluble fractions see Rogers et al. (*15*).

Other information. Additional information on wood chemistry can be found in Kurth (*16*), Lindstedt (*17*), Erdtman (*18*), Swan (*19*), Drew and Pylant (*20*), and Anderson et al. (*14*).

Chemical Composition of Bark

	Institute Paper Chemistry, Project 3212, Report 5	Chang & Mitchell (*21*)
Ash, %	2.2	2.0
Calcium, %	0.6	–
Silica, %	0.16	–

Carbohydrates.	Chang & Mitchell (*21*)
Reducing sugars from extractive-free bark	
Glucose, %	50
Unknown substances, %	3
Galactose, %	7
Mannose	6
Arabinose	26
Xylose	8

Extractives.	Institute Paper Chemistry, Project 3212, Report 5	Chang & Mitchell (*21*)
Alcohol-benzene sol., %	15.7	–
Benzene sol., %	–	28.7
95% alcohol sol., %	–	10.9
Hot water soluble, %	–	5.6
1% NaOH, %	–	29.8

For more information on extractives see Rowe et al. (*24*).

Other Information.

For information on volatile oil see Shrimpton (*22*).

For information on elements in bark, see Harder & Einspahr (*23*).

Pulping

Kraft. The wood is readily reduced, yield is normal, pulp is strong (excellent burst and fair tear), and it has better than usual forming characteristics on the paper machine; it is particularly well suited for blending with coarser fibers; it is easily bleached; it is used for high-grade wrapping papers and fiberboard.

Yield from wood pulped without bark is 47% (kappa no. 31.0); from wood pulped with bark, 45% (kappa no. 31.1).

For kraft pulping information see Wang (*25*) and Hatton and Keays (*26*). Forest-residual chips can supplement conventional chips in a kraft mill in amounts above 10% (*27*).

Mechanical. The wood is readily reduced; color is excellent; it requires 15 to 25% more than white spruce; strength is average. Groundwood is used for newsprint.

Sulfite. The wood is reduced unevenly; the heartwood is difficult to pulp; pulp is strong; yield is normal; the pulp is easily bleached; it is suited for news, wrapping, book, and high-grade printing papers.

Additional information on pulping has been published by Hatch and Holzer (*28*), Thickens and McNaughton (*29*), Wells and Rue (*30*), Martin (*31*), and Horn and Auchter (*32*).

Utilization of Wood and Bark

Use properties of wood. The wood is generally straight and uneven-grained, medium-fine textured, moderately soft, easy to work, holds nails and screws moderately well, has moderate shrinkage, stays in place well, seasons easily, and has conspicuous figure; the heartwood is difficult to penetrate with preservatives, and the sapwood is readily preserved.

Calorific value of wood.

Millions of BTU/air-dry cord	20.1	kcal/kg 4870
Millions of kcal/air-dry cord	5.1	

Calorific value of bark.

Calories per gram	5661
Btu/cubic ft	222,353
Btu/lb	9382
kcal/kg	5595

Other uses of wood. Used for telephone poles, fenceposts, mine timbers, studs, paneling, cabinetry, particle board, flake board, fiberboard, commercial composition boards with layered configurations, insulating boards, railway ties, rough construction, siding, finish, flooring, fuel. Forest residues are used for random-flake flakeboard (*33*).

Literature Cited

1. Tackle, D. USDA, Forest Serv., Intermountain Forest & Range Expt. Sta., Misc. Publ. No. 19, 1959.
2. Critchfield, M. B. Maria Moors Cabot Foundation, Publ. No. 3, 1957.
3. Mason, D. T. Forestry Quart. 13:171(1915).
4. Black, T. M. J. Inst. Wood Sci. No. 11:57-65 (1963).
5. Reid, R. W. and Watson, J. A. Canad. J. Bot. 44(4): 519-25(1966).
6. Smith, J. H. and Kozak, A. Forest Prod. Jour. 21(2): 38-40(1971).
7. Chang, Y. P. Tappi Monograph Series No. 14, 1954, 249 p.
8. U. S. Forest Products Lab. Agriculture Handbook No. 72, 1974.
9. Johnstone, W. D. Inform. Rep. For. Res. Lab., Calgary, No. A-X-29, 1970.
10. Henderson, J. and Petty, J. A. Forestry 45(1): 50-7(1972).
11. Johnstone, W. D. Inform. Rep. For. Res. Lab., Calgary No. A-X-29, 1970, 19 p.
12. Fengel, D. and Grosser, B. Holz Roh- Werkstoff 33:32-4 (1975).
13. Kurth, E. F. Tappi 33(10):507-8(Oct., 1950).
14. Anderson, A. B., Riffer, R. and Wong, A. Phytochem. 8(12):2401-3(Dec., 1969).
15. Rogers, I. H., Harris, A. G. and Rozon, L. R. Can. Dept. Forestry Inform. Rept. VP-X-57: 29 p. (Dec., 1969).
16. Kurth, E. F. Tappi 33:5307(1950).
17. Lindstedt, G. Acta Chem. Scand. 3:759(1949).
18. Erdtman, H. Progress in Organic Chemistry 1:22-63 (1952).
19. Swan, E. P. Forest Prod. J. 16(1):51-4(Jan., 1966).
20. Drew, J. and Pylant, G. D., Jr. Tappi 49(10:430-8) (Oct., 1966).
21. Chang, Y.-P. and Mitchell, R. L. Tappi 38(5):315-20(May, 1955).

22. Shrimpton, D. M. Can. Dept. Forestry Bimo. Res. Note 30(2):12(March/April, 1974).

23. Harder, M. L. and Einspahr, D. W. To be submitted to Tappi.

24. Rowe, J. W., Ronald, R. C. and Nagasampagi, B. A. Phytochem. 11(1):365-369(Jan., 1972).

25. Wang, P. H. Oregon State Univ. Ph.D. Thesis, 1974. 176 p.

26. Hatton, J. V. and Keays, J. L. Pulp Paper Mag. Can. 71(11/12):123-132 (T259-268) (June 5-19, 1970).

27. Hatton, J. V. Brit. Columbia Lumberman, June 1975: 4 p.

28. Hatch, R. S. and Holzer, W. F. TAPPI Monograph No. 4:153(1947).

29. Thickens, J. H. and McNaughton, G. C. U.S. Dept. Agr., Bull. 343. 1916.

30. Wells, S. D. and Rue, J. D. U.S. Dept. Agr., Dept. Bull. 1485. May, 1927. 101 p.

31. Martin, J. S. Tappi 32:534(1949).

32. Horn, R. A. and Auchter, R. J. Paper Trade J. 156(46):55-59(Nov. 6, 1972).

33. Gardner, R. B., Schaffer, E. L. and Ericson, J. R. U.S.D.A. Forest Ser. Res. Paper No. INT-200; 36 p. (March, 1978).

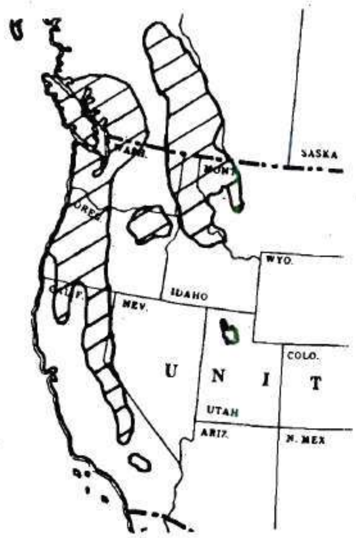
WESTERN WHITE PINE

Scientific Name *Pinus monticola* Dougl.

Synonyms Mountain white pine, Idaho white pine, white pine, silver pine

Family Name Pinaceae

Range Sea level to 3000 ft (910 m) west of the summit of the Cascade Mountains in British Columbia, Washington, and Oregon; 2000-7000 ft (610-2130 m) east of the Cascade summit and in Idaho and Montana; 5000-10,000 ft (1520-3050 m) in California. The species reaches its best development in northern Idaho and adjacent areas in Montana, Washington, and British Columbia. Western white pine forests occupy nearly 3 million acres (1.2 million ha) in northern Idaho, western Montana and eastern Washington (*1*).



Silvics The tree has a long, slightly tapered bole, a short, generally symmetrical and somewhat open crown, and a deep, widespreading system of lateral roots. This species is typically a mountain form, except in the northwestern part of its range. It attains its best development in the Inland Empire region on rich, porous soils in moist valleys and on middle and upper slopes and flats of northerly exposure. Here it is very common and occasionally forms almost pure stands. Elsewhere, an occasional tree or small grove in mixture with other conifers occurs on poorer and drier sites. Its principal associates in the Rockies are western larch, Engelmann spruce, lodgepole pine, grand fir, and subalpine fir; Douglas-fir, western hemlock, grand, noble, and Pacific silver fir in Washington and Oregon; and red fir, Douglas-fir, and lodgepole pine in California. The species is rated as intermediate in tolerance.

Tree Dimensions 150-180 ft (46-55 m) tall and 2.5-3.5 ft (76-107 cm) in diameter.

Pathology Resistance to decay: intermediate.

The most serious insect pest of western white pine is the mountain pine beetle (*Dendroctonus ponderosae*), attacking both mature forests and young overstocked stands. This beetle is generally a primary killer. Other pests of western white pine include the white pine weevil (*Pissodes strobi*) and the pine butterfly (*Neophasia menapia*).

White pine blister rust (*Cronartium ribicola*), widespread through most of the western white pine region, has caused more damage than any other conifer disease. Some stands have been completely destroyed in the western United States and Canada. Other diseases of western white pine include the root rots, *Armillariella mellea* and *Heterobasidion annosum*. White pine pole blight has also made serious inroads on pole-sized trees: the cause and control are not known.

Gross Features of the Wood The wood is moderately soft, moderately light, straight and even grained, medium-coarse textured, slightly resinous, without characteristic odor or taste. The sapwood is nearly white to pale yellowish white, narrow to medium wide. The heartwood is cream colored to light brown or reddish brown, becoming darker on exposure. The earlywood zone is several times wider than the latewood; the latewood zone is distinct with the naked eye but not pronounced. The transition from earlywood to latewood is gradual. In the x-section the rays are very fine and are not distinct to the naked eye unless they include a horizontal resin canal; in the r-section they form a fine, close, inconspicuous fleck. Both longitudinal and horizontal resin canals are normally present. The numerous longitudinal canals, which appear as white flecks to the naked eye, are confined chiefly to the central and outer portions of the growth ring. They are solitary or rarely 2-3 contiguous tangentially, forming more or less prominent streaks along the grain. The horizontal canals are smaller than the longitudinal ones and appear as white, rather prominent wood rays spaced irregularly on the x-section, scarcely visible with a hand lens on the tangential surface. Parenchyma cells are absent.

Microscopic Structure of the Wood

Tracheids. Average 2.9 mm in length and 35-45 μm in diameter. Coarseness of 24 mg/100 m. Bordered pits in one row or occasionally in two on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma large, windowlike, 1-4 (generally 1 or 2) per cross-field, those in the earlywood more or less angled and occupying most of the back wall; ray tracheid pits present.

Resin Canals. Longitudinal, 135-150 μm in diameter; horizontal, less than 80 μm; thin-walled epithelial cells, tylosoids present in heartwood.

Rays. Two types, uniseriate and fusiform; the uniseriate rays are numerous, 1-12+ cells high; the fusiform rays are scattered, with a horizontal resin canal, 2- to 4-seriate in the central portion, tapering to uniseriate margins, up to 20+ cells high; ray tracheids are present in both types of rays, marginal and interspersed, with nondentate inner walls. Volume occupied, approximately 6.5%.

Longitudinal Parenchyma. Absent.

Gross Features of the Bark Smooth, gray green to light gray on young trees; thin [rarely more than 1.25 inches (3.2 cm) thick] even on old trunks where it breaks up into nearly square or rectangular, dark gray or purplish-gray plates separated by deep fissures: inner bark rather narrow, usually about 1/16-inch (0.16 cm) wide but very uneven in width from different sides or parts of the trunk (*2*). Single bark thickness 0.12 inch (0.3 cm) inner bark and 0.38 inch (1.0 cm) outer bark (*3*), with the double bark thickness averaging 6.3% of the diameter outside bark for all sections (*4*).

Microscopic Structure of the Bark (*2*)

Periderm. Rather broad, composed to 2-8 layers of last-formed phelloderm, a layer of phellogen, and 10 or more layers of phellem. Both phellem and phelloderm cells often contain "resinous" substance.

Sieve Cells. Aligned in regular radial rows, often about 10 cells but sometimes only 5 cells continuously in a row, interspersed by 1-3 parenchyma cells; from 1.6-4.1 mm long but mostly about 2.6-3.5 mm; ends chisel-like and gradually pointed.

Sclerenchyma. Absent in the inner bark.

Parenchyma. Strands often of single cells or up to 3 cells in radial rows, aligned more or less in discontinuous tangential lines in cross section; length of strands about the same as that of sieve cells; individual cells often containing "resinous" substance and crystals; radial expansion of parenchyma cells conspicuous only in remote outer bark.

Rays. Of two sizes, uniseriate and fusiform with horizontal resin canals. Uniseriate rays often partially biseriate; mostly about 5-10 cells or 300-400 μm high. Cells in uniseriate rays contain abundant starch grains.

Physical Properties of Bark

Specific gravity (*3*) green volume	Inner bark	0.31
	Outer bark	0.54
Specific gravity (*8*) ovendry weight & volume	Outer bark	0.62
Percent moisture content (*3*) ovendry basis	Inner bark	118
	Outer bark	75

Physical Properties of Wood

Specific gravity	Green volume	0.36
	Airdry volume	0.38
	Ovendry volume	0.42
Density, lb/cu ft (kg/cu m)	Green	35 (560)
	Airdry	27 (430)
	Ovendry	26 (420)
Density, lb/cu ft (kg/cu m)	Ovendry weight per green volume	22 (350)

Percent moisture content, when green

Green basis	35
Oven-dry basis	54

Percent moisture content (*6*) ovendry basis

Heartwood	62
Sapwood	148

Overall decrease in specific gravity with increase in height of tree (*5*).

Percent shrinkage, dried to 0% moisture content: r – 4.1, t – 7.4, v – 11.8 (*6*).

Additional information in this area includes Maeglin and Wahlgren (*7*).

Chemical Composition of Wood

Proximate Analyses

	F.P.L.	F.P.L.(*9*)	Anderson (*10*) Sap	Anderson (*10*) Heart
Lignin, %	26.4	25.4	25.6	25.4
Holocellulose, %	—	64.3	68.5	66.0
C. & B. cellulose, %	59.7	—	59.0	57.7
Alpha-cellulose, %	38.6	42.3	—	—
Pentosans				
Total, %	8.86	7.9	9.2	9.5
In cellulose, %	6.69	7.0	—	—
Mannans, %	6.93	—	—	—
Acetyl, %	1.03	—	—	—
Methoxyl, %	4.56	—	—	—
Solubility in				
Ether, %	4.26	5.6	3.4	3.6
Alcohol-benzene, %	—	8.3	3.4	5.7
1% NaOH, %	14.8	15.6	—	—
Cold water, %	3.16	—	2.3	2.7
Hot water, %	4.49	3.7	4.1	4.5
Ash, %	0.20	0.3	0.2	0.2

	Browning and Isenberg (*11*) Ritter and Fleck (*12*)
Alcohol-benzene solubles, % of wood	8.2
Ether solubles, % of whole wood	5.6
Ether solubles, % of sapwood	3.6
Ether solubles, % of heartwood	5.5

Chemical Composition of Bark

Other Information. Anticopalic acid is a resin acid in the bark (*15*).

Pulping

Groundwood. See Forest Products Laboratory (*16*).

Kraft. The wood is readily reduced, yield is normal, and strength is slightly below average (*9*); for pulp characteristics see Horn and Auchter (*17*). Wood can be pulped by the hydrogen sulfide kraft process (*18*).

Soda. The yield is normal; pulps contained more lignin and were considerably more difficult to bleach than kraft pulps (*9,19*).

Sulfite. See Forest Products Laboratory (*16*).

Utilization of Wood and Bark

The wood can be worked well with tools. The wood is straight grained, easy to work, easily kiln-dried, and stays in place well after seasoning. The wood is moderately light in weight, weak, moderately stiff, moderately soft, moderately low in ability to resist shock, and has a moderately large shrinkage. It is high in ability to hold paint and can be glued readily. It does not split easily in nailing and occupies an intermediate position in nail-holding ability. It is intermediate in decay resistance.

Calorific Value of Wood

Millions of BTU/air-dry cord	18.6
Millions of kg cal/air-dry cord	4.7

Calorific Value of Bark

5040 kg cal/kg

Other uses of wood. It is used for building construction, furniture, plywood, particle board, and fiberboards. Residues are used for pulp and chips.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 445, 1973.

2. Chang, Y. P. USDA, Tech. Bull. No. 1095, 1954.

3. Smith, J. H. G.; Kozak, A. Forest Prod. J. 21(2):38-40(1971).

4. Smith, J. H. G.; Kozak, A. Mimeo of "Thickness and percentage of bark of the commercial trees of British Columbia," University of British Columbia, Faculty of Forestry, 1967.

5. Okkonen, E. A.; Wahlgren, H. E.; Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).

6. USDA, Forest Service. Forest Prod. Laboratory. Agriculture Handbook No. 72, 1974.

7. Maeglin, R. R.; Wahlgren, H. E. USDA, Forest Serv., Res. Pap. FPL-183, 1972.

8. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv., Res. Note FPL-091, 1969.

9. Forest Products Laboratory. Unpublished data.

10. Anderson, A. B. Ind. Eng. Chem. 36:662(1944).

11. Browning, B. L.; Isenberg, I. H. *In* Wise, L. E. and Jahn, E. C., eds., Wood Chemistry. New York: Reinhold, 1952. p. 1264.

12. Ritter, G. J.; Fleck, L. C. Ind. Eng. Chem. 14:1050(1922); 15:1055 (1923); 18:608(1926).

13. Lindstedt, G. Acta Chem. Scand. 3:1147(1949).

14. Drew, J.; Pylant, G. D., Jr. Tappi 49(10):430-8 (Oct. 1966).

15. Zinkel, D. F.; Toda, J. K.; Rowe, J. W. Phytochem. 10(5):1161-3 (May 1971).

16. Forest Products Laboratory. Tech. Note No. 191. Dec., 1939. 3 p.

17. Horn, R. A.; Auchter, R. J. Paper Trade J. 156(46):55-9(Nov. 6, 1972).

18. Vinje, M. G.; Worster, H. E. Tappi 53(6):1082-6(June, 1970).

19. Martin, J. S.; Bray, M. W. Tech. Assoc. Papers 24:596(1941); Paper Trade J. 111(25):35(Dec. 19, 1940).

SUGAR PINE

Scientific Name *Pinus lambertiana* Dougl.

Synonyms California sugar pine

Family Name Pinaceae

Range Oregon, California, extreme western Nevada. 1000-4000 ft (300-1220 m) elevation in the north; 4000-7000 ft (1220-2130 m) in central California; and 7000-10,000 ft (2130-3050 m) in the south.

Silvics The tree has a long, massive, clear, cylindrical bole, a short crown composed of several large, horizontal branches and a well-developed lateral root system. This species is typical of the transition zone and reaches its best development on the west slopes of the Sierra Nevada in northern and central California at 4500-5500 ft (1370-1680 m) elevation. It is always found in mixture, principally with ponderosa and Jeffrey pines, Douglas-fir, white fir, incense-cedar, and giant sequoia. Further north, it is often found with digger pine, ponderosa pine, Douglas-fir, tanoak, California black oak, bigleaf maple, and dogwood usually below 4000 ft (1220 m) elevation. In the south it becomes alpine in habit. The species is rated as intermediate in tolerance.

Tree Dimensions The world's largest pine; 170-180 ft (52-55 m) tall and 2.5-3.5 ft (76-107 cm) in diameter.

Pathology Resistance to decay: intermediate.

Sugar pine is very susceptible to white pine blister rust (*Cronartium ribicola*). However, spread and intensification of the disease have been slow in the southern part of its range, (*1*). The most serious wood-rotting fungi attacking sugar pine are *Phellinus pini* and *Fomes laricis*. *Arceuthobium campylopodum* is the dwarf mistletoe parasite of sugar pine.

The principal insect enemies of sugar pine are the mountain pine beetle (*Dendroctonus ponderosae*), the fivespined ips (*Ips confusus*), and the flatheaded pine borer (*Melanophila gentilis*). The mountain pine beetle, in particular, may cause severe damage and loss in both young sugar pine stands and mature forests.

Gross Features of the Wood The wood is moderately soft, light, straight and even grained, relatively coarse textured, slightly resinous, has a faint noncharacteristic odor, often exudes a sugary substance when green, but is without characteristic taste when dry. The sapwood is nearly white to pale yellow-white and narrow to medium in width. The heartwood is light brown to pale red-brown, frequently discolored with brown stain. The earlywood zone is several times wider than the latewood zone; the transition between them is gradual. The growth ring is distinct because of the darker latewood. In the x-section the rays are very fine and are not distinct with the naked eye unless they include a horizontal resin canal; in the r-section they form a fine, close, inconspicuous fleck. Both longitudinal and horizontal resin canals are normally present. The numerous longitudinal canals are conspicuous, confined largely to the central and outer portions of the ring, solitary or rarely 2-3 contiguous tangentially, and appear as prominent dark streaks along the grain. The horizontal canals appear as rather prominent wood rays spaced at irregular intervals on the x-section and are visible with a hand lens as brownish specks on the t-section. Parenchyma cells are absent.

Microscopic Structure of the Wood

Tracheids. Average 5.9 mm in length and 40-50 μm in diameter. Coarseness of the earlywood and latewood of holo- and alpha-cellulose pulps determined by Sastry and Wellwood (2). Bordered pits in one to two rows on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma large, windowlike, 1-4 (generally 2 or 3) per cross-field, those in the earlywood rounded to elliptical, and more or less widely spaced. Volume occupied, approximately 94%.

Resin Canals. Longitudinal, 175-225 μm in diameter; horizontal, less than 80 μm; thin-walled epithelial cells, tylosoids present in the heartwood. Volume occupied, <1%.

Rays. Two types, uniseriate and fusiform; the uniseriate rays are numerous, 1-12+ cells high; the fusiform rays are scattered, with a horizontal resin canal, 2- to 4-seriate in the central portion, tapering to uniseriate margins, up to 30+ cells high; ray tracheids are present in both types of rays, marginal and interspersed, with nondentate inner walls. Volume occupied, approximately 6%.

Longitudinal Parenchyma. Absent.

Gross Features of the Bark Dark green, thin, and smooth on young stems, grayish brown to purplish brown on old trunks, 1.5-4 inches (3.8-10.2 cm) thick, and broken into irregular, superficially scaly ridges separated by deep fissures. A sweet substance, pinite, exudes from bark wounds.

Microscopic Structure of the Bark (*3*)

Periderm. Small, tangentially short and often curved.

Sieve Cells. Usually about 4.5 mm long.

Sclerenchyma. Absent in the inner bark.

Parenchyma. Short and broad, containing very large-sized starch grains.

Resin Canals. Comparatively more abundant than in hard pines.

Physical Properties of Wood

Specific gravity	Green volume	0.35
	Air-dry volume	0.36
	Oven-dry volume	0.38
Density, lb/cu ft (kg/cu m)	Green	52 (833)
	Air-dry	25 (400)
	Oven-dry	24 (384)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	22 (352)

Overall decrease in specific gravity with increase in height of tree (*4*).

Percent shrinkage, dried to 0% moisture content (*5*): r – 2.9, t – 5.6, v – 7.9.

Percent moisture content, when green	
Green basis	58
Oven-dry basis	137

Percent moisture content (*5*) oven-dry basis	
Heartwood	98
Sapwood	219

Additional information in this area includes Maeglin and Wahlgren (*6*).

Physical Properties of bark

Specific gravity oven-dry weight & volume (*7*)	0.38
Specific gravity of the outer bark oven-dry weight, volume at 13 ± 2% moisture content (*8*)	0.34

Chemical Composition of Wood

Proximate Analyses

	Anderson (*9*) Sap	Anderson (*9*) Heart
Lignin, %	26.8	24.8
Holocellulose, %	68.5	62.5
C. & B. cellulose, %	58.7	54.1
Ash, %	0.2	0.2
Pentosan, %	10.4	9.5
Solubility in		
Ether, %	3.1	4.5
Alcohol-benzene, %	3.8	12.0
Cold water, %	1.7	8.4
Hot water, %	3.1	10.3

Carbohydrates

	Smith and Zavarin (*10*) Sap	Heart	Schorger (*11*)	Dore (*12*)
Glucose, %	0.06	tr.	–	–
Fructose, %	0.05	–	–	–
Sucrose, %	0.03	–	–	–
Raffinose, %	0.02	–	–	–
Stachyose, %	tr.	–	–	–
Arabinose, %	–	tr.	–	–
Mannan	–	–	4.67	6.63

Other Information. See Drew and Pylant (*13*). Pinite, the methyl ether of d-inositol, is found in the aqueous extract or sometimes as an efflorescence on seasoned lumber. For information on fatty and resin acids and monoterpenes see Anderson, *et al.* (*14*).

Chemical Composition of Bark

Proximate Analysis

	Chang and Mitchell (*15*)
Ash, %	0.6
Methoxyl, %	2.45
Solubility in	
Benzene, %	1.5
95% Alcohol, %	21.7
Hot water, %	3.2
1% NaOH, %	36

Carbohydrates

Reducing sugars from extractive-free bark	
Glucose, %	69
Unknown substances, %	1
Galactose, %	6
Mannose, %	8
Arabinose, %	7
Xylose, %	0

Pulping

Groundwood. Pitch limits the proportion in which the pulps can be used.

Kraft. The wood is readily reduced, yield is normal, and strength is fair; it is used for wrapping papers and fiberboard (*16,17*).

Sulfite. Sapwood is readily reduced, and heartwood is reduced with difficulty; the yield is normal, color is dull greenish-brown, strength is fair, and the pulp is shivy and harsh; it is used for wrapping papers (*17*).

Utilization of Wood and Bark

Use properties of wood. The wood is straight-grained, comparatively uniform in texture, easy to work with tools, has very low shrinkage, is readily seasoned without warping or checking, and stays in place well. Sugar pine is moderately weak, moderately soft, and not stiff. It takes and holds paint well, is intermediate in decay resistance, does not split easily in nailing, and has moderate nail-holding ability.

Chemical uses of wood. Alcohol production: 53 gallons of 95% alcohol/ton by the Madison process.

Other uses of wood. It is used almost entirely for lumber, for building construction, boxes and crates, sash and doors, general millwork, and foundry patterns.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 271, 1965, 762 p.
2. Sastry, C. B. R.; Wellwood, R. W. Tappi 55(6):901-3(1972).
3. Chang, Y.-P. USDA, Tech. Bull. No. 1095, 1954, 86 p.
4. Okkonen, E. A.; Wahlgren, H. E.; Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).
5. U.S. Forest Prod. Lab. Agriculture Handbook No. 72, 1974.
6. Maeglin, R. R.; Wahlgren, H. E. USDA, Forest Serv., Res. Paper FPL 183, 1972.
7. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv., Res. Note FPL-091, 1969.
8. Cassens, D. L. Forest Products J. 24(4):40-5(1974).

9. Anderson, A. B. Ind. Eng. Chem. 36:662(1944).

10. Smith, L. V.; Zavarin, E. Tappi 43(3):218-21 (March, 1960).

11. Schorger, A. W. J. Ind. Eng. Chem. 9:748(1917).

12. Dore, W. H. J. Ind. Eng. Chem. 12:476(1920).

13. Drew, J.; Pylant, G. D., Jr. Tappi 49(10):430-8 (Oct., 1966).

14. Anderson, A. B.; Riffer, R.; Wong, A. Phytochem. 8(5):869-72(May, 1969).

15. Chang, Y.-P.; Mitchell, R. L. Tappi 38(5):315-20(May, 1955).

16. Hatch, R. S.; Holzer, W. F. TAPPI Monograph No. 4:153(1947).

17. Swanson, W. H. Tech. Assoc. Papers 10:54(1927); Paper Trade J. 83(22):46(Nov. 25, 1926).

EASTERN LARCH

Scientific Name *Larix laricina* (Du Roi) K. Koch.

Synonyms Tamarack, American larch, Alaska larch, hackmatack, black larch

Family Name Pinaceae

Range One of the widest ranges of American conifers; northeastern United States to Alaska.

Tree Dimensions 50-75 ft (15-23 m) tall and 14-20 inches (36-51 cm) in diameter. The species outgrows all other swamp species in the boreal forest (*1,2*).

Pathology Resistance to decay: intermediate

Eastern larch is fairly free of stem diseases, although it can be affected by the heart rot, *Phellinus pini*. The butt

and root rot fungi reported on eastern larch include *Armillariella mellea* and *Phaeolus schweinitzii*. They are not of economic importance, however. The common foliage diseases are rusts, which do little damage. They include *Hypodermella laricis* and two *Melampsora* spp.

Silvics The tree is small to medium sized with a long, clear, cylindrical bole, open pyramidal crown, and a shallow, wide-spreading root system. Eastern larch is a characteristic tree of cool bogs and swamps, especially in the southern parts of its range. Farther north best growth is made on rich, moist but well-drained, loamy soils along streams, lakes, swamps, seep areas, and shallow layers of muck or well-decomposed peat over mineral soils, although it will grow on much drier sites. Prolonged flooding will kill the tree. In bogs black spruce is its chief associate; on drier land it occurs with black spruce, white spruce, northern white-cedar, balsam fir, aspen, balsam poplar, white birch, and jack pine. Unlike most conifers, eastern larch sheds its needles every autumn. The species is rated as very intolerant.

The larch sawfly (*Pristiphora erichsonii*) can be a serious defoliator of larch, feeding on needles of older twigs. Marked growth loss occurs after 4-6 years of attack with mortality in 6-9 years. The larch casebearer (*Coleophora laricella*), an introduced species, has become a serious defoliator of larch. The most serious damage is done in the spring as the larvae feed on newly developing foliage. Trees may be killed after two years of complete defoliation. Other, less serious pests include the eastern larch beetle (*Dendroctonus simplex*) and the white-marked tussock moth (*Hemerocampa leucostigma*).

Gross Features of the Wood The sapwood is whitish and the heartwood is yellowish brown to russet brown. The wood is moderately hard and moderately heavy. It is more or less oily with a somewhat greasy feel and has no characteristic taste or odor. It is medium fine-textured. The earlywood usually occupies at least three quarters of the growth ring; the transition from earlywood to latewood is abrupt, and the latewood varies from narrow to wide. Flat grain boards exhibit a distinct growth ring figure because of the conspicuous latewood. In the x-section the rays are very fine, not distinct with the unaided eye, and form a fine, close, inconspicuous fleck on the radial surface. Both longitudinal and horizontal resin canals are present. The longitudinal canals are small, inconspicuous, not visible with the unaided eye or appearing as whitish or dark flecks, sparse, confined largely in the central and outer portions of the ring, solitary or 2 to several contiguous tangentially. The horizontal canals are smaller than the longitudinal ones and appear with a hand lens as somewhat broader, whitish rays spaced irregularly on the x-section, and not visible or barely visible with a hand lens in the t-section. Longitudinal parenchyma are not visible.

Cross section of eastern larch, exhibiting a slower-than-normal growth rate. Transition between earlywood and latewood is abrupt. Wood is medium textured. Magnification, 20X.

Microscopic Structure of the Wood

Tracheids. Average 3.6 mm (1.7-5.6 mm) in length and 25-35 μm in diameter. Weight factor (unbleached kraft) of 1.00. Tracheids in the latewood occasionally have spiral thickening. Bordered pits in 1-2 rows on radial walls; tangential pits present in the last few rows of latewood tracheids; pits leading to ray parenchyma small, quite uniform in size, with distinct border (piceoid), 1-12 (generally 4-6) per cross-field, often in double horizontal rows; ray tracheid pits present; volume occupied, approximately 89%. Fegel (*3*) found that root tracheids averaged 2.1 mm. According to Crist, *et al.* (*4*), coarseness values for 4-year-old eastern larch averaged 22.3 mg/100 m. Balatinecz and Farrar (*5*) discuss tracheid development in larch seedlings under controlled environment.

Resin Canals. Longitudinal, average 60-90 μm in diameter; horizontal, less than 25 μm. Thick-walled epithelial cells and occasional tylosoids. Volume occupied, <1%.

Rays. Two types, uniseriate or rarely in part biseriate, and fusiform. The uniseriate rays are numerous and 1-20+ cells in height; the biseriate rays are very sparse and scattered, or absent. The scattered fusiform rays, which include a horizontal resin canal, are 2- to 3-seriate in the central portion, tapering to uniseriate margins, up to 20+ cells in height. Ray tracheids are present in both types of rays, marginal and rarely interspersed, nondentate inner walls; marginal usually in one row. Volume occupied, approximately 10%. Timell (*6*) has made observations on rays in compression wood.

Longitudinal Parenchyma. Terminal and very sparse, or absent. Volume occupied, <1%.

Gross Features of the Bark Thin and smooth on young stems, later 0.5-0.75 inch (1.3-1.9 cm) thick; gray to reddish brown; inner bark dark reddish-purple; inner bark often wider than last-formed rhytidome layer. Additional information on bark volume can be found in Millikin (*7*).

Microscopic Structure of the Bark (*8*)

Periderm. Comparatively thin, usually composed of about 5 or more layers of phellem, a layer of phellogen, and 2-5 layers of last-formed phelloderm. Phellem cells entirely thin-walled or alternating with a few layers of thick-walled cells which were probably transformed from phelloderm; thin-walled cells rather uniform in thickness and like ordinary cork cells; thick-walled cells rather irregular in shape, with very narrow lumen and distinct simple pits; cells of both types variable from 10-30 μm tangentially and 10-15 μm radially in cross section and about 20-30 μm high.

Sieve Cells. Found in radial rows of 5-10 cells interspersed by a layer of parenchyma or fibers; about 30-50 μm in tangential dimension and 15-30 μm in radial dimension, varying from 2.0-4.6 mm long, but mostly about 3 mm; ends usually gradually pointed but often blunt.

Phloem Fibers. Very sporadic, about 2-8 mature fibers in a square mm, mostly solitary; rather short, varying in length from 0.7-1.5 mm, mostly about 1 mm; outline in cross section oval to irregularly rounded; diameter variable according to position being cut, mostly about 40-60 μm. Individual cells mostly straight but occasionally slightly branched, ends gradually pointed or abrupt; cell walls very thick with lamellate layers, narrow lumen, visible simple pits.

Parenchyma. Often occur singly or 2-4 in a short radial row, tangentially more or less continuously aligned; parenchyma strands are about same height as adjacent sieve cells. Individual cells about same size and shape in cross section as sieve cells, usually radially elongated at outer part of inner bark, about 100 μm high; end walls more or less rounded. Cells contain abundant resinous substance and isodiametric crystals.

Rays. Two sizes, uniseriate rays and fusiform rays with horizontal resin canals. Uniseriate rays rather high, mostly about 15 cells or 300 μm but sometimes up to 40 cells or 700 μm high; individual cells about 50-70 μm in radial dimension and about 20 μm high, usually containing resinous substance and starch grains. Albuminous cells conspicuous and appear in most ray sections close to the cambial region; slightly higher than ordinary ray cells to twice as high, mostly about 20-30 μm in radial dimension. Fusiform rays variable in size at different stages of development and position in tangential sections; local expansion or vertical elongation through radial course often conspicuous; canals present with well-defined border of 2-3 layers of epithelial cells.

According to Alfieri and Evert (*9*), cambial activity in eastern larch occurs from late April to early September. They also discuss the structure of eastern larch phloem and its seasonal development.

Physical Properties of Wood

Specific gravity	Green volume	0.49
	Air-dry volume	0.53
	Oven-dry volume	0.56
Density, lb/cu ft (kg/cu m)	Green	47 (753)
	Air-dry	37 (593)
	Oven-dry	35 (561)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	31 (497)

Overall decrease in specific gravity with increase in height of tree (*10*).

Percent shrinkage, dried to 0% moisture content: r – 3.7, t – 7.4, v – 13.6.

Percent moisture content, when green

Green basis	34
Oven-dry basis	52

Additional publications in this area include Besley (*11*), Maeglin (*12*), Pronin (*13*), and Wahlgren, *et al.* (*14,15*).

Physical Properties of Bark

Specific gravity oven-dry weight & volume (*16*)	0.63

Additional information on bark quality of juvenile eastern larch grown under intensive culture can be found in Crist, *et al.* (*4*).

Chemical Composition of Wood

Proximate Analyses

	F.P.L. (*17*)	Browning and Isenberg (*18*)
Lignin, %	26.2	–
Holocellulose, %	65.4	–
Alpha-cellulose, %	44.4	–
Pentosans		
Total, %	8.3	–
In cellulose, %	8.1	–

Solubility in		
Alcohol-benzene, %	2.0	2.0
Ether, %	0.6	0.6-0.7
1% NaOH, %	12.4	–
Hot water, %	4.6	–
Ash, %	0.3	

McMillen, *et al.* (*19*) have also analyzed this species.

Extractives. The wood contains up to 4% of a water-soluble arabogalactan, white powder, $[a]^{20}_{D}$ 13°, reducing value about 34 mg of cuprous oxide per 500 mg of polysaccharide; it yields about 82% galactose and 12.6% arabinose on hydrolysis. This is probably not homogeneous, although evidence in favor of the formula $[(C_5H_8O_4)\ (C_6H_{10}O_5)_6]_n$ has been presented. It forms a benzoate, an acetate, and a propionate that may be fractionated (*20,21*). Flavones are probably in the wood (*22*). For information on heartwood extractives see Giwa and Swan (*23*). For the percent composition of extractives see Drew and Pylant (*24*).

Other Information. For information on fatty acids and resin acids see Swan (*25*). For chemical composition of hemicelluloses in normal and compression wood ray cells, see Hoffman (*26*).

Pulping

Kraft. The wood is readily reduced; the pulp is strong, and yield is normal. It is used for high-grade wrapping and bag papers and fiberboard (*27*).

Mechanical. The wood is readily reduced to a satisfactory pulp. The pulp is light grayish green in color and requires 40-50% more power than spruce. The yield is 82%. It is similar to jack pine in pulping characteristics and probably could be used as a partial substitute for spruce (*27-30*). The groundwood pulp is similar to that obtained from southern pine, except that its color is darker. The pulp can be brightened to levels required for newsprint by single-stage bleaching with peroxide or hydrosulfite.

Neutral Sulfite Semichemical. Chidester (*31*) studied the influence of acid, neutral, and alkaline pretreatment methods and bleaching on yield and pulp properties; he also reports on uses of pulps.

Sulfite. The wood is reduced with difficulty. The color is dark and the pulp is shivy. It is fairly easily bleached, and the yield is low (*27*).

Utilization of Wood and Bark

Use properties of wood. The wood is hard, very strong, and stiff. It has extreme variations in strength. It is somewhat coarse-grained and brittle and inclined to warp.

Calorific Value of Wood

Million of BTU/air-dry cord	24
Million of kg cal/air-dry cord	5.8

Calorific Value of Bark

9010 BTU/o.d. lb
5006 kg cal/o.d. kg

Other uses of wood. Lumber is used for house framing, tanks, shipbuilding, mine timbers, poles, and posts.

Literature Cited

1. Conway, V. M. Ecol. Monog. 19:173-206(1949).

2. Roe, E. I. USDA, Forest Serv., Lake States For. Expt. Sta. Tech. Note 389, 1952, 1 p.

3. Fegel, A. C. N.Y. State Coll. For., Tech. Bull. 55, 1941, 20 p.

4. Crist, J. B.; Dawson, D. H.; Nelson, J. A. *In* Proc. TAPPI Forest Biology/Wood Chemistry Conf., held June 20-22, 1977, Madison, WI, p. 211-16.

5. Balatinecz, J. J.; Farrar, J. L. *In* USDA, Forest Serv. Res. Pap. NC-23, 1968, p. 28-36.

6. Timell, T. E. Holz Roh-Werkstoff 30(7):267-73(1972).

7. Millikin, D. E. Pulp Paper Mag. Can. 56(13):106-8(1955).

8. Chang, Y. P. USDA, Tech. Bull. No. 1095, 1954, 86 p.

9. Alfieri, F. J.; Evert, R. F. Bot. Gaz. 134(1):17-25(1973).

10. Okkonen, E. A.; Wahlgren, H. E.; Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).

11. Besley, L. Pulp Paper Res. Inst. Can., Tech. Rept. No. 489 (Woodlands Res. Index No. 182), 1966, 30 p.

12. Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-202, 1973, 40 p.

13. Pronin, D. USDA, Forest Serv. Res. Pap. FPL-161, 1971, 16 p.

14. Wahlgren, H. E.; Hart, A. C.; Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-61, 1966, 22 p.

15. Wahlgren, H. E.; Baker, G.; Maeglin, R. R.; Hart, A. C. USDA, Forest Serv. Res. Pap. FPL-95, 1968, 12 p.

16. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.

17. FPL. Unpublished data.

18. Browning, B. L.; Isenberg, I. H., *In* Wise, L. E. and Jahn, E. C., eds., Wood Chemistry. New York: Reinhold. p. 1264. 1952.

19. McMillen, J. M.; Gortner, R. A.; Schmitz, H.; Bailey, A. J. Ind. Eng. Chem. 30:1407(1938).

20. Peterson, F. C.; Barry, A. J.; Unkauf, H.; Wise, L. E. J. Am. Chem. Soc. 62:236(1940).

21. Wise, L. E.; Hamer, P. L.; Peterson, F. C. Ind. Eng. Chem. 25:184(1933).

22. Kanehira, R. J. Forestry 19:736(1921).

23. Giwa, S. A. O.; Swan, E. P. Wood Fiber 7(3):216-21(Fall, 1975).

24. Drew, J.; Pylant, G. D., Jr. Tappi 49(10):430-8(1966).

25. Swan, E. P. Can. Dept. Forestry, Inform. Rept. VP-X-115:24 p. (Aug., 1973).

26. Hoffman, G. C. State Univ. Coll. of Forestry at Syracuse Univ., Ph.D. Thesis, 1971. 397 p.

27. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485. May, 1927. 101 p.

28. McGovern, N. N.; Schafer, E. R.; Martin, J. S. TAPPI Monograph No. 4:130(1947).

29. Running, K. D. Pulp Paper Mag. Can. 41(2):18(1940).

30. Thickens, J. H.; McNaughton, G. C. USDA, Bull. No. 343. 1916.

31. Chidester, G. H. Proc. Forest Prods. Res. Soc. 3:197(1949).

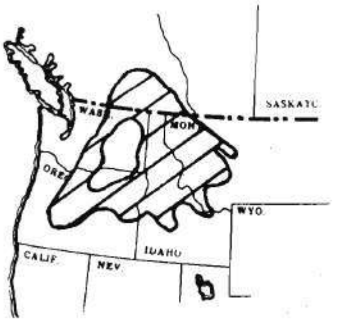
WESTERN LARCH

Scientific Name *Larix occidentalis* Nutt.

Synonyms Hackmatack, Montana larch, mountain larch, tamarack, western tamarack

Family Name Pinaceae

Range Occurs only in the Upper Columbia River Basin of North America. It grows from southeastern British Columbia through western Montana and its range includes the east slopes of the Cascades in Washington and north-central Oregon and the Wallowa and Blue Mountains of northeastern Oregon and southeastern Washington (*1*). The species covers 3 1/2 million acres (1.4 million ha) at elevations of 2000-7000 ft (610-2130 m) above sea level.



Silvics This long-lived tree has a clear, tapered bole (often swollen-butted), a short, narrow, open, pyramidal crown, and a deep, wide-spreading root system. It grows best on deep, moist, porous soils in high valleys and on mountain slopes of northern and western exposure. It is often the most abundant species in the larch-Douglas-fir forests of the northern Rockies, where it is also associated with western white pine and, at higher elevations, with lodgepole pine, Engelmann spruce, and subalpine fir. Other associates are western hemlock, grand fir, ponderosa pine and, occasionally, western red-cedar. This species is rated as very intolerant and is dominant in old-growth mixed stands.

Tree Dimensions 140-180 ft (43-55 m) tall and 3-4 ft (91-122 cm) in diameter. Height growth is rapid and diameter growth moderate until the trees are 75-100 years old (*1*).

Pathology Resistance to decay: intermediate

A serious disease is dwarf mistletoe (*Arceuthobium laricis*), occurring throughout the range of western larch. A high proportion of stands are infested, and mortality and growth loss is common. Three other important diseases affecting western larch include brown trunk rot (*Fomes officinalis*), red ring rot (*Phellinus pini*) and needlecast caused by *Hypodermella laricis*.

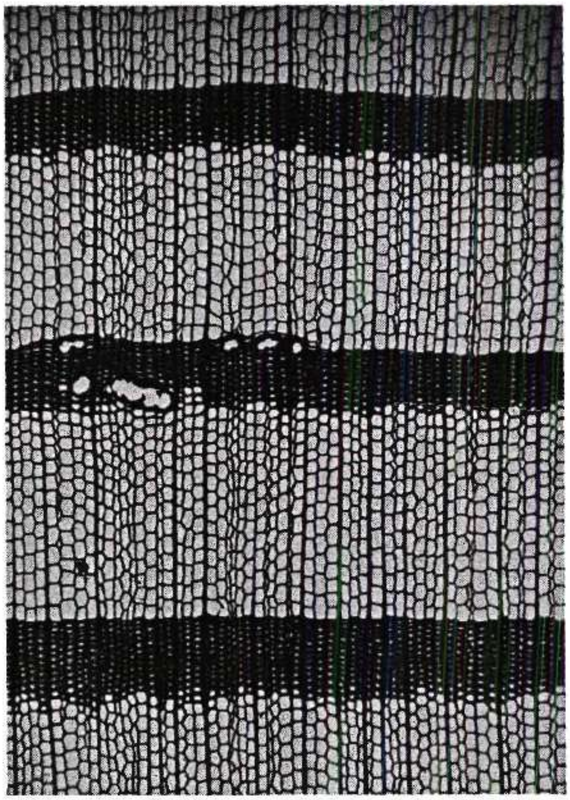
The larch casebearer (*Coleophora laricella*) is a European insect that feeds on new foliage in early spring and is the major insect pest of western larch. Another serious pest is the western spruce budworm (*Choristoneura occidentalis*), which reduces height growth and affects tree form. Other insects causing occasional heavy damage include the larch sawfly (*Pristiphora erichsonii*) and the larch budmoth (*Zeiraphera griseana*). Also causing some damage are the two-lined larch sawfly (*Anoplonyx laricivorus*), the western larch sawfly (*A. occidens*) and the larch looper (*Semiothisa sexmaculata incolorata*).

Gross Features of the Wood The wood of western larch is moderately hard, moderately heavy, slightly resinous, straight grained, coarse textured, with a characteristic oily appearance and greasy feel, but without characteristic odor or taste. The sapwood is white to pale straw brown and very narrow. The heartwood is russet or reddish brown. The latewood zone is normally very narrow, sharply delineated and conspicuous to the unaided eye which makes the growth ring quite distinct. The earlywood zone usually constitutes at least 70% of the growth ring. The transition from earlywood to latewood is abrupt. In the x-section the rays are very fine, not distinct to the unaided eye, and form a fine, close, inconspicuous fleck on the radial surface. Both longitudinal and horizontal resin canals are present. The longitudinal canals are small, inconspicuous, not visible to the unaided eye or appearing as whitish or dark flecks, sparse, confined mostly to the latewood, solitary or 2 to several contiguous tangentially. The smaller horizontal canals appear, with a hand lens, as somewhat broader, whitish rays spaced irregularly on the x-section and are invisible or barely visible with a hand lens on the tangential surface. Longitudinal parenchyma cells are not visible. Sapwood thickness of western larch is covered in a publication by Lassen and Okkonen (*2*).

Microscopic Structure of the Wood

Tracheids. Average 5.0 mm in length and 40-50 µm in diameter. (Thick tracheid walls.) Weight factor (unbleached kraft) 1.20 and coarseness of 32.5 mg/100 m. Those tracheids in the latewood occasionally have spiral thickening. Bordered pits in 1-2 rows on the radial walls;

tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma small, quite uniform in size, with distinct border (piceoid), 1-10 (generally 4-6) per cross-field, often in double horizontal rows; ray tracheid pits present. Volume occupied, approximately 89%.



Cross section of a slow-growing western larch, showing abrupt transition between earlywood and latewood. Normal resin canals are present. Magnification, 20X.

Resin Canals. Longitudinal, average, 60-90 μm in diameter; horizontal, less than 25 μm. Thick-walled epithelial cells and occasional tylosoids. Volume occupied, <1%.

Rays. Two types, uniseriate or rarely in part biseriate, and fusiform. The uniseriate rays are numerous and 1-20+ cells high; the biseriate rays are very sparse and scattered, or absent. The scattered fusiform rays, which include a horizontal resin canal, are 2- to 3-seriate in the central portion, tapering to uniseriate margins, up to 20+ cells in height. Ray tracheids are present in all types of rays, marginal and rarely interspersed, nondentate inner walls; marginal, usually in one row. Volume occupied, approximately 10%.

Longitudinal Parenchyma. Terminal and very sparse, or absent. Volume occupied, <1%.

Gross Features of the Bark The bark is thin and gray on young trees, becomes thick, reddish-brown and scaly with age, forming deep irregular fissures in very old trees. The thick outer bark provides good insulation against forest fires and can be removed from living trees without harm to the tree. On cross section scales are outlined by distinct reddish-brown periderm, are nearly parallel to one another and are brittle and easily peeled off. The inner bark is rather narrow, usually about 0.1 inch thick, and light yellowish-brown in contrast to the outer bark. In a study by Smith and Kozak (*3*), double bark thickness at breast height averaged 2.3 inches (5.6 cm) and may develop up to 6 inches (15 cm) in thickness (*4*).

Microscopic Structure of the Bark

Young Trees or Branches. The bark is composed of a layer of cutinized epidermal cells, 2-3 layers of small, compact and uniformly thickened cells, and a layer of large cells with thin walls and large cell cavities where canal formations appear. The periderm in young stems and branches is mainly thin-walled phellem and 1-2 layers of phelloderm merging into the cortex. The cortex is composed of ordinary cortex cells, large resin cells, vertical resin canals, and sclerenchyma cells. Sieve cells, parenchyma, rays and resin canals from the newly differentiated fusiform rays form the secondary phloem of the young trees.

Mature Trees.

Periderm. The periderm is developed rather uniformly, the main portions of two adjacent periderms running mostly parallel. The radial distance between two periderms is about 0.08 inch (0.2 cm) with a vertical extent about 1-1.5 inches (2.5-3.7 cm) and tangential dimensions of scales are about 0.5 inch (1.3 cm) (*5*). Composed of 2-4 layers of phelloderm, a layer of phellogen, and usually 3-5 layers of thin-walled phellem cells, periderm cells on cross section are rectangular in shape and slightly larger than phloem parenchyma cells. Phelloderm cells are parenchymatous in nature and the cell walls occasionally become "lignified." Broad bands of thick-walled, strongly lignified cells often appear outside the layers of regular thin-walled, suberized phellem cells or alternate with them.

Sieve Cells. Aligned in radial rows in the secondary phloem and interrupted about every fifth cell by tangential lines of parenchyma and sporadically distributed sclereidlike fibers. Sieve cells are usually rectangular or slightly rounded on cross section, with tangentia dimensions varying from 30-70 μm; radial dimensions from 15-35 μm; and lengths from 2.6-4.8 mm and comprise approximately 67% of the elements of the secondary phloem (*4*). They are commonly obliterated in the outer bark.

Phloem Fibers. Relatively short and often branched. They appear only very sporadically, about 0-5 per sq mm, and are usually absent in most parts of the inner bark. Their length varies from 0.8-1.9 mm, usually about 1.5 mm. Cell walls are thick with distinct laminate layers in the secondary wall. Sclereidlike phloem fibers occupy approximately 2% of the tissue elements in the secondary phloem (*5*).

Parenchyma. Aligned tangentially or sporadically, they are usually about the same size and shape on cross section as the sieve cells, but usually radially expanded at the outer part of the bark. Rather uniform in cell wall thickness, individual cells vary from 70-180 μm in height and contain tanniferous substances and crystals of calcium oxalate.

Rays. Both uniseriate and fusiform. Uniseriate rays are usually 12 cells or 250 μm high with conspicuous erect ray margin cells. Fusiform rays vary in size and contain well-developed horizontal resin canals of thin-walled epithelial cells. Resin canals become conspicuously enlarged at the outer part of the inner bark and often closely aligned in a vertical row in the outer bark. The dilation of the fusiform rays and the expansion of the horizontal resin canals in the outer bark makes the transformation of the secondary phloem tissues conspicuous in the rhytidome.

Physical Properties of Wood

Specific gravity	Green volume	0.48
	Air-dry volume	0.52
	Oven-dry volume	0.54
Density, lb/cu ft (kg/cu m)	Green	48 (769)
	Air-dry	36 (577)
	Oven-dry	34 (545)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	30 (481)

Overall decrease in specific gravity with increase in height of tree (*6*).

Increment cores taken from trees that were thinned 15 years earlier indicated that specific gravity increased and these increases could be related to the reduction in stand competition (*7*).

Percent shrinkage, dried to 0% moisture content: r – 4.2, t – 8.1, v – 13.2.

Percent moisture content, when green

Green basis	37
Oven-dry basis	58

Percent moisture content oven-dry basis (*8*)

Heartwood	54
Sapwood	110

Additional information in this area includes Mitchell (*9*) and USDA, Forest Service (*10*).

Physical Properties of Bark

Specific gravity green volume	Inner bark	0.37
	Outer bark	0.33
	Total bark	0.33
Density (100% moisture content)	Green weight/ green volume	0.61
Percent moisture content oven-dry basis (*3*)	Inner	99
	Outer	44

Chemical Composition of Wood

Proximate Analyses

	F.P.L.	F.P.L.(*11*)
Lignin, %	–	26.8
Holocellulose, %	–	66.5
C. & B. cellulose, %	57.8	–
Alpha-cellulose, %	–	50
Ash, %	0.23	0.4
Pentosans		
Total, %	12.5	7.8
In cellulose, %	8.94	–
Mannan, %	5.13	–
Acetyl, %	0.71	–
Methoxyl, %	5.03	–
Solubility in		
Alcohol-benzene, %	–	1.4
Ether, %	0.81	0.4
1% NaOH, %	22.1	13.4
Hot water, %	12.6	4.9
Cold water, %	10.6	–

Carbohydrates. The water-soluble polysaccharide (9-18%) is called arabogalactan, which has $[\alpha]^{20}_{D}$ 12°; it has the approximate composition $[(C_5H_8O_4) - (C_6H_{10}O_5)]_n$; it yields substantially 84-85% galactose and about 12% arabinose on hydrolysis. Uronic acid is either absent or is present in an insignificant amount. The arabogalactan, despite uniform composition, is probably not homogeneous. It forms esters that may be fractionated and a methyl ether. The reducing value is about 35 mg of cuprous oxide per 500 mg of polysaccharide (*12-20*).

Extractives. The tannin content is 6.7% (*21*); for other information on extractives see Drew and Pylant (*22*); flavones are probably present (*23*).

Chemical Composition of Bark

Proximate Analyses

	Chang and Mitchell (*24*)	The Institute of Paper Chemistry Project 3212 Report 5
Ash, %	1.6	2.4
Methoxyl, %	3.14	
Solubility in		
Alcohol-benzene	—	14.4
Benzene, %	1.3	
95% alcohol, %	14.8	
Hot water, %	3.8	
1% NaOH, %	22.7	
Calcium, %	—	0.6
Silica, %	—	0.26

Other Information. For information on elements in bark, see Harder and Einspahr (*25*).

Pulping

Kraft. The wood is readily reduced; yield is low; strength is average (tear strength is high and burst strength is low) (*26*). For pulp characteristics see Horn and Auchter (*27*).

Mechanical. The wood is reduced with difficulty; the pulp is brown; the pulp is rather coarse and not suitable for the generally acceptable grades of groundwood pulp (*26,28*).

Sulfite. The wood is reduced with difficulty and very unevenly; it is dark; the pulp is brash, shivy, and the yield is slightly low (*26*).

Utilization of Wood and Bark

Use properties of wood. The wood has a greasy feeling and has no particular odor or taste. It is moderately heavy, has strong bend and endwise compression strength, is stiff, and it is moderately high in shock resistance. Although it splits rather easily, it has a moderately high nail-holding capacity when blunt-pointed nails are used. It is easy to glue and takes stain readily and does not hold paint especially well. It occasionally contains growth-ring crack. It is easy to dry and exudes sugars when dried at high temperatures. It is only moderately resistant to decay. Because of the high levels of natural sugars, it is not well suited for concrete forms.

Calorific Value of Wood

Million of BTU/air-dry cord	26.5
Million of kg cal/air-dry cord	6.6

Calorific Value of Bark

4860 kg cal/kg

Chemical uses of wood. Chips are a source of galactan for the chemical and pharmaceutical industries; the chips are then pulped.

Other uses of wood. It is important in construction that requires a wood having high strength and hardness. It is used interchangeably with Douglas-fir for general construction lumber or plywood. It is used for paneling, flooring, industrial crating, and pallets. It is used extensively for transmission poles and telephone poles. It is sometimes used for mine shaft guides. Residues from sawmills and plywood mills are used in pulp mills.

Literature Cited

1. USDA, Forest Service, Agriculture Handbook No. 271, 1965, 762 p.

2. Lassen, L. E.; Okkonen, E. A. USDA, Forest Serv. Res. Pap. FPL-124, 1969.

3. Smith, J. H. G.; Kozak, A. Forest Prod. J. 21(2):38-40(1971).

4. Schmidt, W. C.; Shearer, R. C.; Roe, A. L. USDA, Forest Serv. Tech. Bull. No. 1520, 1976.

5. Chang, Y.-P. New York, TAPPI Monograph Series No. 14, 1954.

6. Okkonen, E. A.: Wahlgren, H. E.: Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).

7. Lowery, D. P.: Schmidt, W. C. USDA, Forest Serv. Res. Note INT-70, 1967.

8. U.S. Forest Products Lab. Agriculture Handbook No. 72, 1974.

9. Mitchell, H. L. Proc., Society of Am. Foresters, Denver, CO, 1964, p. 169-79.

10. USDA, Forest Service USDA, Forest Serv. Res. Pap. FPL-27, 1965.

11. Forest Products Laboratory. Unpublished data.

12. Hirst, E. L.; Jones, J. K. N.; Campbell, W. G. Nature 147:25(1941).

13. Husemann, E. J. Prakt. Chem. 155:13(1940).

14. Mitchell, R. L.; Ritter, G. J. Forest Products Lab., Mimeo. R1771. May, 1950. 7 p. J. Forestry 49:112(1951).

15. Mosimann, H.; Svedberg, T. Kolloid-Z. 100:99(1942).

16. Peterson, F. C.; Barry, A. J.; Unkauf, H.; Wise, L. E. J. Am. Chem. Soc. 62:2361(1940).

17. Schorger, A. W.; Smith, D. F. J. Ind. Eng. Chem. 8:494(1916).

18. White, E. V. J. Am. Chem. Soc. 64:2838(1942).

19. Wise, L. E.; Hamer, P. L.; Peterson, F. C. Ind. Eng. Chem. 24:184(1933).

20. Wise, L. E.; Peterson, F. C. Ind. Eng. Chem. 22:362(1930).

21. Benson, H. K.; Jones, F. M. J. Ind. Eng. Chem. 9:1096(1917).

22. Drew, J.; Pylant, G. D., Jr. Tappi 49(10):430-8 (Oct., 1966).

23. Kanehira, R. J. Forestry 19:736(1921).

24. Chang, Y.-P.; Mitchell, R. L. Tappi 38(5):315-20(May, 1955).

25. Harder, M. L.; Einspahr, D. W. To be submitted to Tappi.

26. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485. May, 1927. 101 p.

27. Horn, R. A.; Auchter, R. J. Applied Polymer Symposium No. 28, 529-39(1976).

28. Thickens, J. H.; McNaughton, G. C. USDA, Bull. No. 343. 1916.

WHITE SPRUCE

Scientific Name *Picea glauca* (Moench) Voss.

Synonyms Canadian spruce, skunk spruce, cat spruce, Black Hills spruce, western white spruce

Family Name Pinaceae

Range Northern United States and transcontinental in Canada from Newfoundland to Alaska.

The spruce-fir type covers nearly 11 million acres (4.5 million ha) in New England and New York (*1*) and 3 million acres (1.2 million ha) in the Lake States (*2*).

Silvics The tree has a long, straight, tapering bole, an irregular cylindrical crown, and a shallow, spreading root system. White spruce forms extensive pure stands and also occurs in mixtures with quaking aspen, white birch, balsam fir, jack pine, black spruce, lodgepole pine, and red spruce. The best growth is on moist, sandy loam or alluvial soils; although found on many different sites, this species is especially typical of stream banks, lake shores, and adjacent slopes. Apparently, white spruce is more exacting in its nutrient requirements than associated spruces or pines. Some seed is generally produced every year with occasional years of heavy production. The species is rated as tolerant.

Tree Dimensions 60-70 ft (18-21 m) tall and 18-24 inches (46-61 cm) in diameter. Heights of 110 ft (34 m) are not uncommon.

Pathology

White spruce is surprisingly devoid of serious fungus diseases (*3*). However, it is attacked to a certain degree by several needle rusts (*Chrysomyxa* spp.) and heart rot fungi. The red ring rot fungus (*Phellinus pini*) is probably the most important of these.

White spruce has a number of insect pests. Chief among these are the spruce budworm (*Choristoneura fumiferana*), the European spruce sawfly (*Diprion hercyniae*), and the eastern spruce beetle (*Dendroctonus piceaperda*). In many instances, the eastern spruce beetle will attack trees weakened by the spruce budworm. Several species of Ips also attack white spruce, including *Ips* *perturbatus* and *Ips interpunctus.* White spruce is susceptible to fire damage and windthrow, especially on shallow soils.

Gross Features of the Wood Similar to red spruce, the wood is lustrous, nearly white to pale brown with an indistinct heartwood, is usually straight grained, light to moderately light, and very uniform in appearance. Growth rings are distinct, delineated by the contrast between the latewood and the earlywood of the succeeding ring. The earlywood zone is usually several times wider than the somewhat darker latewood zone.

Microscopic Structure of the Wood

Tracheids. Average 3.5 mm in length and 25-30 μm in diameter. Weight factor (unbleached kraft) of 0.90. Average cell wall thickness varies from earlywood fibers of less than 1.0 μm to latewood fibers which measure 3-4 μm. Lee (*4*) found that fast-grown white spruce had tracheids approximately 10% longer than those of normally grown trees. Britt (*5*) has additional information on fiber coarseness.

Rays. Fine and numerous, uniseriate rays are 1-16+ cells in height. Fusiform rays, up to 16+ cells in height, are scattered, with one or rarely two transverse resin canals. Ray tracheids are present in both types of rays and usually restricted to one row on the upper and lower margin.

Resin Canals. Resin canals are lined with thick-walled epithelial cells and those in the heartwood may occasionally be occluded with tylosoids. The longitudinal resin canals average 50-90 μm in diameter and the transverse, less than 30 μm. See additionally the description for red spruce.

Gross Features of the Bark Ashy brown with thin, small scales, white spruce bark is usually not over 0.5 inch (1.3 cm) thick. Periderm layers are distinct and sporadic. Sclerenchyma groups are visible in the inner bark and quite distinct at the outer bark. Rather narrow, the inner bark is generally 1/16 to 1/8 inch (0.16-0.32 cm) wide. According to Smith and Kozak (*6*), interior spruce, which included white, black and Engelmann spruce, averaged 6.7% double bark thickness as a percentage of the diameter outside bark for all sections. Other publications dealing with bark thickness and volume include Hale (*7*) and Millikin (*8*).

Microscopic Structure of the Bark

Periderm. Composed of 2-3 layers of phelloderm, a layer of phellogen and 1-3 layers of thin-walled phellem cells, alternating with 1-3 layers of thick-walled "corky" phellem cells. The number of phellem cells in a periderm layer is variable, often over 20 cells. Phellem cells are rectangular in cross section, 10-20 μm and 20-30 μm in radial and tangential dimensions, respectively. Newly-formed phelloderm cells are approximately the same size and merge into the parenchyma cells of the secondary phloem. Occasionally, the cells become lignified.

Inner Bark. Made up of sieve cells, parenchyma cells, sclereids, ray cells, and horizontal resin canals.

Sieve Cells. Usually 3.8 mm long, they are aligned in radial rows of approximately 14-16 cells, interspersed by 1-3 tangential lines of parenchyma cells. Sieve cells appear rectangular in cross section, their radial and tangential dimensions averaging approximately 10-20 μm and 10-30 μm, respectively, with a cell wall thickness of approximately 1-2 μm. In the outer part of the inner bark, and in the outer bark, the sieve cells are obliterated or crushed.

Parenchyma. Parenchyma strands are about the same length as the adjacent sieve cells. Individual cells are 50-150 μm high.

Sclereids. Sclereids are transformed from the phloem parenchyma and are aggregated in small groups. At the outer part of the inner bark, sclereid groups of 10 or more cells appear sporadically. The size of the larger groups may have a radial dimension of 0.15-3.0 mm, a tangential dimension of 0.5-1.0 mm, and a height of 0.5-2.0 mm. Individual cells, with diameters of about 15-25+ μm, have very thick walls, are irregular in shape, and sometimes are branched.

Rays. Phloem rays are both uniseriate and fusiform. Uniseriate rays are usually 10-15 cells or 200-300 μm high. Marginal erect cells or albuminous cells are present in almost every ray close to the cambium region. Fusiform rays with horizontal resin canals are common.

Resin Canals. Usually 2-5 layers of thin-walled epithelial cells line the ducts of the resin canals which average approximately 250 μm in diameter.

Physical Properties of Wood

Specific gravity	Green volume	0.37
	Air-dry volume	0.40
	Oven-dry volume	0.42
Density, lb/cu ft (kg/cu m)	Green	35 (561)
	Air-dry	28 (448)
	Oven-dry	26 (416)

Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	23 (368)

Overall increase in specific gravity with increase in height of tree (9).

Studies of wide and narrow growth rings showed no definite relationship between fast or abnormal growth and density of the wood (10).

Percent shrinkage, dried to 0% moisture content: r – 4.7, t – 8.2, v – 13.7.

Percent moisture content, when green

Green basis	33
Oven-dry basis	50

Additional information in this area includes Bendtsen (*11*), Besley (*12*), Maeglin (*13*), Pronin (*14*), Wahlgren, *et al.* (*15,16*).

Physical Properties of Bark

Specific gravity green volume	Inner bark	–
	Outer bark	0.43
	Total bark	0.39
Density (100% moisture content)	Green weight/ green volume	0.83
Specific gravity (*17*) oven-dry weight & volume		0.65

According to Erickson (*18*), the green specific gravity of green bark was less than the dry specific gravity of dry bark.

Additional information in this area can be obtained from Hale (*7*).

Chemical Composition of Wood

Proximate Analyses

	Chidester and Billington (*19*)		F.P.L.	Clermont and Schwartz (*20*)	Young (*22*)[e]
Lignin, %	30.9	27.8	–	26.96[a]	27.1
Holocellulose, %	–	–	–	72.0[b]	–
C. & B. cellulose, %	61.1	60.6	61.85	–	–
Alpha-cellulose, %	43.0	42.1	–	50.24[c]	–
Cellulose, %	–	–	–	–	48.5
Hemicellulose, %	–	–	–	16.39[a]	–
Ash, %	–	–	–	0.22	0.3
Pentosans					
Total, %	11.5	12.1	12.5	8.00	–
In cellulose, %	–	–	10.4	–	–
Mannan, %	–	–	–	–	11.6
Acetyl, %	–	–	–	1.08	1.3
Methoxyl, %	–	–	5.30	5.07	–
Xylan, %	–	–	–	–	6.8
Moisture content, %	–	–	–	6.69	–
Solubility in					
Alcohol-benzene, %	1.8	2.3	–	–	–
Ether, %	0.8	1.1	1.36	2.12	–
1% NaOH, %	12.2	10.7	11.6	12.5	–
Hot water, %	3.2	2.1	2.14	2.22	–
Cold water, %	–	–	–	1.36	–
Acetic acid, %	–	–	1.59	–	–
Uronic anhydride, %	–	–	–	4.48	3.6
In hemicelluloses					
Pentosans, %	–	–	–	33.5[d]	–
Uronic anhydride, %	–	–	–	16.3[d]	–

Hexosans (by difference), %	–	–	–	50.2[d]	–

[a]Corrected for ash.
[b]Corrected for ash, lignin, and extractives.
[c]Corrected for ash and lignin.
[d]As % of moisture-free hemicelluloses.
[e]Based on extractive-free wood.

Browning and Isenberg (*21*) found 0.8% to be soluble in alcohol-benzene, while 0.4% was soluble in ether.

Schorger (*23*) found the mannan content to be 7.12%. Rogers, *et al.* (*24*) found the moisture content to be 45.88%. Rapson *et al.* (*25*) found the ash content to be 0.43% and the content of alcohol-benzene extractives to be 2.2%. Hajny and Ritter (*26*) studied the constituents of Cross and Bevan cellulose and holocellulose.

Carbohydrates

	Young (*22*)
Galactan, %	1.2
Glucan, %	46.5
Araban, %	1.6

	Rogers *et al.* (*24*)
Solubility in	
Acetone, %	1.91
Diethyl ether, %	1.343
Petroleum ether, %	1.035
Insolubility in	
Diethyl ether, %	0.534
Petroleum ether, %	0.308

Extractives. For the percent composition of wood, see Drew and Pylant (*27*). For acetone- and petroleum ether-soluble extractives, see Rogers, *et al.* (*24*). For information on fatty acids and resin acids, see Swan (*28*). Conidendrin has been reported (*29*).

Chemical Composition of Bark

Proximate Analyses

	Rapson *et al.* (*25*)	Corder (*30*)
Ash, %	4.2	3.5
Calcium, %	1.2	
Silica, %	0.14	
Fixed carbon, %		24.0
Volatile, %		72.5

Extractives. Rapson, *et al.* (*25*) found the alcohol-benzene extractives to be 16.0%. This level was also confirmed in The Institute of Paper Chemistry, Project 3212, Report 3.

For information on elements in bark, see Harder and Einspahr (*31*).

Pulping

Alkaline sulfite. Pulping with 0.2-2% sodium borohydride gave pulps stronger than kraft pulps. Pulps bleached by successive treatment with Cl, NaOH, and ClO_2 were also stronger than kraft pulps (*32*).

Kraft. The wood is readily reduced, the yield is normal, and the pulp is strong and of fine texture. It is used for high-grade wrapping papers and fiberboard (*33*). Kraft pulp at a permanganate number of 20 gave an unscreened yield of 48% based on oven-dry wood. Bark gave a pulp yield of 21%. For pulping information see Hatton and Keays (*34*), and for properties of unbleached paper see Keays and Hatton (*35*). Polysulfide added to kraft liquor increases the yield (*36*).

Mechanical. The wood is readily reduced, and the pulp is of excellent color and has standard strength. It requires 60-80 HP-days/ton of power. It is used for all products requiring groundwood (*33,37-42*). Groundwood can be bleached with ZnS_2O_4; a two-stage bleach process with H_2O_2 followed by ZnS_2O_4 gives 73 brightness. Groundwood can also be bleached with aluminum dithionite (*43*).

Neutral Sulfite Semichemical. More chemical is consumed than with kraft pulping (*44*). Wood pulped with liquor containing varying amounts of combined sulfur dioxide and about 6% total sulfur dioxide required 21-26% bleach for yields varying from 42-54% (*19*).

Sulfite. The wood is reduced readily, the yield is normal, and the pulp is strong, of fine texture and excellent color. It is occasionally somewhat pitchy. It is used for newspaper, wrapping paper, book papers, high-grade printing papers, and bond papers. The prevalence of knot dirt in unbleached pulp is not as apparent as with black spruce (*19, 44-47*).

Acid bisulfite. A yield of 51% was obtained from shredded chips brought to maximum temperature in 30 min and cooked for a total of 120 min; for other information, including solubles, see Nolan (*48*). Continuous pulping is possible (*49*).

Utilization of Wood and Bark

Use properties of wood. The wood is light in weight, has good strength for its weight, and does not impart odor or color. It is soft and easily worked. It is noted for resilience. It is not very durable.

Calorific Value of Wood

Million of BTU/air-dry cord	16.2
Million of kg cal/air-dry cord	4.1

Calorific Value of Bark

BTU/ft^3	228,992
kg cal/m^3	1633
BTU/o.d. lb	8530
kg cal/o.d. kg	4739

Chemical uses of wood. In New England an oil is prepared by the steam distillation of the needles and twigs of white spruce. This oil is used as a perfume in greases and shoe blackings and in liniments and other medicinal preparations.

Spruce gum is collected from trees after three years of aging and is used in medicinal preparations and in chewing gum.

Chemical uses of foliage. The foliage is used with *Pinus contorta* as an adhesive extender in polyphenolic resin.

Other uses of wood. The wood is used for boxes and crates, light and medium construction, sounding boards, ladder rails, canoe paddles, oars, and scaffolding. The pliable roots are used for lacing birch bark canoes and for making woven baskets. Charcoal is made from pyrolyzed white spruce and jack pine bark.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 445, 1973, 114 p.
2. Ohmann, L. F.; Batzer, H. O.; Buech, R. R.; Lotherner, D. C.; Perala, D. A.; Schipper, A. L., Jr.; Verry, E. S. USDA, Forest Serv. Gen. Tech. Rept. No. NC-48, 1978, 34 p.
3. USDA, Forest Service. Agriculture Handbook No. 271, 1965, 762 p.
4. Lee, H. N. Can. For. J. 13:1439-40(1917).
5. Britt, K. W. Tappi 48(1):7-11(1965).
6. Smith, J. H. G.; Kozak, A. Mimeographed article "Thickness and percentage of bark of the commercial trees of British Columbia," University of British Columbia, Faculty of Forestry, 1967 (personal communication).
7. Hale, J. D. Pulp Paper Mag. Can. 56(13):113-17(1955).
8. Millikin, D. E. Pulp Paper Mag. Can. 56(13):106-8(1955).
9. Okkonen, E. A., Wahlgren, H. E.; Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).
10. Tsoumis, G.; Passialis, C. Wood Sci. and Technol. 11(1):33-8(1977).
11. Bendtsen, B. A. USDA, Forest Serv. Res. Pap. No. FPL-237, 1974, 28 p.
12. Besley, L. Pulp Paper Res. Inst. Can., Woodlands Res. Index No. 182, 1966, 30 p.
13. Maeglin, R. R. USDA, Forest Serv. Res. Pap. No. FPL-202, 1973, 40 p.
14. Pronin, D. USDA, Forest Serv. Res. Pap. No. FPL-161, 1971, 16 p.
15. Wahlgren, H. E.; Hart, A. C.; Maeglin, R. R. USDA, Forest Serv. Res. Pap. No. FPL-61, 1966, 22 p.
16. Wahlgren, H. E.; Baker, G.; Maeglin, R. R.; Hart, A. C. USDA, Forest Serv. Res. Pap. No. FPL-95, 1968, 12 p.

17. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.

18. Erickson, J. R. USDA, Forest Serv. Res. Note No. NC-141, 1972, 3 p.

19. Chidester, G. H.; Billington, P. S. Tech. Assoc. Papers 20:251(1937); Paper Trade J. 104(6):39(Feb. 11, 1937).

20. Clermont, L. P.; Schwartz, H. Pulp Paper Mag. Can. 52(13):103-5(Dec., 1951).

21. Browning, B. L.; Isenberg, I. H., *In* Wise, L. E. and Jahn, E. C., eds., Wood Chemistry. New York: Reinhold. p. 1264. 1952.

22. Young, H. E. Personal communication.

23. Schorger, A. W. J. Ind. Eng. Chem. 9:748(1917).

24. Rogers, I. H.; Harris, A. G.; Rozon, L. R. Can. Dept. Forestry, Inform. Rept. VP-X-57:29 p. (Dec., 1969).

25. Rapson, W. H.; Wayman, M.; Anderson, C. B. Pulp Paper Mag. Can. 66(5):T255-71(May, 1965).

26. Hajny, G. J.; Ritter, G. J. Tech. Assoc. Papers 24:595(1942); Paper Trade J. 113(13):83(Sept. 24, 1941).

27. Drew, J.; Pylant, G. D., Jr. Tappi 49(10):430-8 (Oct., 1966).

28. Swan, E. P. Can. Dept. Forestry, Inform. Rept. VP-X-115: 24 p. (Aug., 1973).

29. Erdtman, H. Svensk Papperstidn. 47:155(1944).

30. Corder, S. E. Properties and uses of bark as an energy source. Oregon State Univ., Forest Res. Lab. Res. Paper No. 31, April, 1976. 21 p.

31. Harder, M. L.; Einspahr, D. W. To be submitted to Tappi.

32. Sanyer, N.; Tomoyuki, I.; Keller, E. L. Tappi 47(6):323-35(June, 1964).

33. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485. May, 1927. 101 p.

34. Hatton, J. V.; Keays, J. L. Pulp Paper Mag. Can. 71(11/12):123-32 (T259-68) (June 5-19, 1970).

35. Keays, J. L.; Hatton, J. V. Tappi 54(10):1721-4(Oct., 1971).

36. Sanyer, N.; Laundrie, J. F. Tappi 47(10):640-52(Oct., 1964).

37. Libby, C. E.; O'Neil, F. W. Tappi 33:161(1950).

38. Libby, C. E.; O'Neil, F. W. New York State College of Forestry, Tech. Publ. 72. 42 p.

39. Schafer, E. R.; Hyttinen, A. Tappi 33:335(1950).

40. Schafer, E. R.; Hyttinen, A. Paper Trade J. 131(5):26(Aug. 3, 1950).

41. Thickens, J. H. USDA, Forest Service Bull. No. 127. 1913.

42. Thickens, J. H.; McNaughton, G. C. USDA, Bull. No. 343. 1916.

43. Smith, J. W.; Cooper, D. F.; Seeley, L. E.; Anderson, C. B. CPPA Tech. Sect. Proc. 1971:D79-85.

44. McGovern, J. N.; Keller, E. L. Pulp Paper Mag. Can. 49(9):93-100(Aug., 1948).

45. McGovern, J. N. Paper Trade J. 103(20):29(1936).

46. Miller, R. N.; Swanson, W. H. Tech. Assoc. Papers 7:32(1924); Paper Trade J. 78(15):178(April 10, 1924).

47. Swanson, W. H. Tech. Assoc. Papers 10:54(1927); Paper Trade J. 83(22):46(Nov. 25, 1926).

48. Nolan, W. J. Tappi 44(7):484-93(July, 1961).

49. Nolan, W. J. Tappi 44(11):753-62(Nov., 1961).

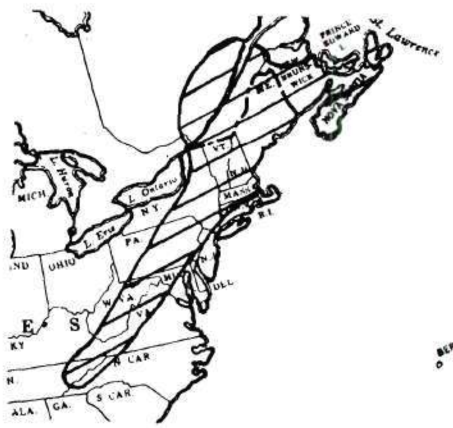
RED SPRUCE

Scientific Name *Picea rubens* Sarg.

Synonyms Yellow spruce, West Virginia spruce, he-balsam, eastern spruce

Family Name Pinaceae

Range Nova Scotia and southern Quebec and Ontario south to Maine, eastern New York, central Pennsylvania and northern New Jersey. It is also found in the Appalachian Mountains and is especially characteristic of the mountainous regions in northern New York and northern New England. The spruce-fir type covers nearly 11 million acres (4.5 million ha) in New England and New York (*1*).



Silvics This long-lived tree has a long, cylindrical bole, a short, broad crown, and a shallow, widespreading root system. Red spruce occurs in pure stands or in groups, and also in mixture. It is found in swamps or bogs with black spruce, tamarack, balsam fir, and red maple, but grows much faster on better drained flats associated with balsam fir, hemlock, white pine, and yellow birch. Pure groups are found on upper slopes where the soil is very thin and rocky. The best growth, however, takes place in scattered trees which occur throughout the northern mixture on higher ground. In general, acid, sandy loam soils with a great deal of moisture support the best spruce. Good seed crops occur every 3-8 years with light crops during the intervening years. A seedbed of moss and decayed wood with a plentiful supply of moisture and some shade is necessary for good reproduction. The rate of growth is strongly influenced by light conditions. Although trees will live in dense shade for many years, they require nearly full light for best development. The species is rated as tolerant.

Tree Dimensions Medium-sized tree; 60-75 ft (18-23 m) tall and 12-24 inches (30-61 cm) in diameter.

Pathology Resistance to decay: low+

The species has few diseases. The wood rotting fungi *Phellinus pini* and *Phaeolus schweinitzii* are usually confined to overmature or damaged trees (*2*). The main foliage diseases are rusts, caused by *Chrysomyxa* spp.

The most important insect enemy is the spruce budworm (*Choristoneura fumiferana*). Damage to red spruce from this insect pest is heavier if the stand contains balsam fir. Two sawflies attack red spruce, the European spruce sawfly (*Diprion hercyniae*) and the yellow-headed spruce sawfly (*Pikonema alaskensis*). The eastern spruce beetle (*Dendroctonus obesus*) occurs throughout the eastern United States, generally attacking windfalls, overmature, and weakened trees.

Red spruce is very susceptible to fire damage and windthrow.

Gross Features of the Wood The wood of red spruce is moderately light, soft to moderately soft, lustrous, fine to medium textured, even- and usually straight-grained, nonresinous, without characteristic odor or taste. The sapwood is not distinguishable from the heartwood; it is nearly white to pale yellow in color. The earlywood zone is several times wider than the latewood; the latewood zone is distinct with the unaided eye but not pronounced, so that flat grain boards show only a faint growth ring figure. In the x-section the rays are very fine and are not distinct with the unaided eye unless they include a horizontal resin canal, and in the radial surface they form a fine, close, inconspicuous fleck. Both longitudinal and horizontal resin canals are normally present. The longitudinal canals, which are not usually visible with the unaided eye but appear as white flecks with a hand lens, are solitary or 2 to several contiguous in a tangential row and irregularly distributed. The horizontal canals are smaller than the longitudinal ones but are visible with a hand lens on the transverse surface. Longitudinal parenchyma cells are absent. Young, *et al.* (*3*) discuss the weight of wood substance for components of red spruce.

Microscopic Structure of the Wood

Tracheids. Average 3.3 mm (1.3-4.9 mm) in length and 25-30 μm in diameter. Weight factor (unbleached kraft) of 0.90. Bordered pits in one row or very rarely paired on the radial walls; tangential pitting present in last few rows of latewood tracheids; pits leading to ray parenchyma small, uniform in size, oval to angular (piceoid), with distinct border, 1-6 (generally 2-4) per cross field; ray tracheid pits present. Volume occupied, approximately 95%. Shepard and Bailey (*4*) found for one 50-year-old red spruce that tracheid length increased with height up to a given point and then decreased toward the top. MacMillan (*5*) found that tracheids laid down in free-growing trees were at every age longer than those laid down in suppressed trees.

Resin Canals. Longitudinal, 40-90 μm in diameter; horizontal, less than 30 μm; thick-walled epithelial cells, occasional tylosoids. Volume occupied, <1%.

Rays. Two types, uniseriate or rarely in part biseriate, and fusiform. The uniseriate rays are numerous, 1-17 cells (303 μm) in height; biseriate rays very sparse and scattered, or absent; the fusiform rays are scattered, with one or rarely two horizontal resin canals, 2- to 3-seriate in the central portion, tapering to uniseriate margins, up to 40 cells (680 μm) in height; ray tracheids are present in all types of rays, usually restricted to one row on the upper and lower margins, with nondentate inner walls. Five rays per mm tangentially on x-section and 28 rays per sq mm on t-section. Volume occupied, approximately 5%.

Longitudinal Parenchyma. Absent.

Gross Features of the Bark 0.25-0.5 inch (0.6-1.3 cm) thick, separating into close, irregular, grayish to reddish-brown scales with reddish-brown inner layers; volume, about 10%. According to Young (*6*), the bark of various components as a percent of the complete tree bark amounted to: branches and unmerchantable top – 14%, merchantable bole – 50%, and stump and roots – 36%. A publication on bark volume is Millikin (7).

Microscopic Structure of the Bark (*8*)

Periderm. Composed of both very thick- and thin-walled cells.

Sclereids. Occur in small groups and the groups are rather sporadic and sometimes absent in the inner bark of comparatively young trees.

Rays. Fusiform rays with horizontal resin canals are always present.

Parenchyma. The occurrence of parenchyma at certain intervals between two radial rows of sieve cells seems rather constant.

Physical Properties of Wood

Specific gravity	Green volume	0.38
	Air-dry volume	0.41
	Oven-dry volume	0.43
Density, lb/cu ft (kg/cu m)	Green	34 (545)
	Air-dry	28 (448)
	Oven-dry	27 (432)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	24 (384)

Overall increase in specific gravity with increase in height of the tree (*9*).

Percent shrinkage, dried to 0% moisture content: r – 3.8, t – 7.8, v – 11.8.

Percent moisture content, when green

Green basis	30
Oven-dry basis	43

Additional information in this area included Bendtsen (*10*), Besley (*11*), and Wahlgren, *et al.* (*12,13*).

Physical Properties of Bark

Specific gravity oven-dry weight & volume (*14*)	0.60

Chemical Composition of Wood

Proximate Analyses

	Richter (*15*) Sap	Richter (*15*) Heart	Jahn and Wise (*16*)
Lignin, %	28.4	29.8	30.0
C. & B. cellulose, %	–	–	57.3
Alpha-cellulose, %	–	–	44.7
Ash, %	0.25	0.93	–
Pentosans			
Total, %	9.1	10.5	11.5
In cellulose, %	–	–	7.1
Mannan, %	–	–	4.7
Methoxyl, %	–	–	4.56
Solubility in			
Alcohol, %	1.11	1.06	1.25
Benzene, %	–	–	0.61

Ether, %	0.72	0.87	–
Hot water, %	2.52	3.39	–

In addition, Hajny and Ritter (*17*) have studied the constituents of Cross and Bevan cellulose and holocellulose. Schreuder (*18*) has studied the chemical composition.

Extractives. Conidendrin could not be found in branches from young trees (*19*).

Other Information. The chemical composition of wood has been reported by Young *et al.* (*20*) and Young and Guinn (*21*).

Chemical Composition of Bark

Proximate Analysis

	Milliken (*7*)
Ash, %	3.3
Fixed carbon, %	23.7
Volatile, %	72.9

Other Information. For a chemical analysis of bark, see Millikin (*7*) and Young (*6*).

Pulping

Kraft. The wood is readily reduced; the yield is normal, and the strong pulp has a fine texture; it is used for high-grade wrapping papers and fiberboard (*22*). For physical and mechanical properties see Stone and Clayton (*24*).

Mechanical. The wood is readily reduced; the pulp is of excellent color and standard strength; it requires 60-80 HP-days/ton of power; it is used wherever groundwood is required (*22*).

Nitric Acid. This process can be used for logging residues (*23*).

Soda. The pulp is nearly identical to kraft pulp; for physical and mechanical properties see Stone and Clayton (*24*).

Sulfite. The wood is readily reduced; the pulp is strong, of fine texture and excellent color, and is in normal yield; it is occasionally somewhat pitchy; it is easily bleached to excellent white; it is used for newsprint, wrapping paper, book papers, high-grade printing paper, and bond papers. The prevalence of knot dirt in unbleached pulp is not so apparent as with black spruce (*22,25-27*).

Utilization of Wood and Bark

Use properties of wood. The wood is similar to white spruce; although it is slightly harder, heavier, and stronger, the difference is so small that no attempt is made to separate them in marketing.

Calorific Value of Wood

Million of BTU/air-dry cord	18.1
Million of kg cal/air-dry cord	4.6

Calorific Value of Bark

8630 BTU/oven-dry lb
4795 kg cal/o.d. kg

Other uses of wood. The wood is used for boxes and crates, light and medium construction, sounding boards, ladder rails, canoe paddles, oars, scaffolding, and boatbuilding.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 445, 1973, 114 p.

2. USDA, Forest Service. Agriculture Handbook No. 271, 1965, 762 p.

3. Young, H. E.; Hoar, L.; Ashley, M. Tappi 48(8):466-9(1965).

4. Shepard, H. B.; Bailey, I. W. Proc. Soc. Am. For. 9:522-5(1914).

5. MacMillan, W. B. J. Forestry 23:34-42(1925).

6. Young, H. E. Forest Prod. J. 21(5):56-9(1971).

7. Millikin, D. E. Pulp Paper Mag. Can. 56(13):106-8(1955).

8. Chang, Y.-P. USDA, Tech. Bull. No. 1095, 1954, 86 p.

9. Okkonen, E. A.; Wahlgren, H. E.; Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).

10. Bendtsen, B. A. USDA, Forest Serv. Res. Pap. FPL-237, 1974, 28 p.

11. Besley, L. Pulp Paper Res. Inst. Can., Tech. Rept. No. 489 (Woodlands Res. Index No. 182), 1966, 30 p.

12. Wahlgren, H. E.; Hart, A. C.; Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-61, 1966, 22 p.

13. Wahlgren, H. E.; Baker, G.; Maeglin, R. R.; Hart, A. C. USDA, Forest Serv. Res. Pap. FPL-95, 1968, 12 p.

14. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.

15. Richter, G. A. Ind. Eng. Chem. 33:78(1941).

16. Jahn, E. C.; Wise, L. E. Paper Ind. 10:244(1928).

17. Hajny, G. J.; Ritter, G. J., Tech. Assoc. Papers 25:595(1942); Paper Trade J. 113(13):83(Sept. 24, 1941).

18. Schreuder, H. R. M.S. Thesis, Syracuse, NY: State Univ. Coll. Forestry at Syracuse Univ.; June, 1966: 269 p.

19. Erdtman, H. Svensk Papperstidn. 47:155(1944).

20. Young, H. E.; Carpenter, P. N.; Altenberger, R. A. Maine Agricultural Experiment Station, Tech. Bull. No. 20. 88 p. Oct., 1965.

21. Young, H. E.; Guinn, V. P. Tappi 49(5):190-7 (May, 1966).

22. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485. May, 1927. 101 p.

23. Kurrle, F. L. Tappi 46(4):267-72(April, 1963).

24. Stone, J. E.; Clayton, D. W. Pulp Paper Mag. Can. 61(6):T307-13(June, 1960).

25. Richter, G. A. Ind. Eng. Chem. 33:532(1941).

26. Schur, M. O.; Baker, R. E. Tech. Assoc. Papers 25:453(1942); Paper Trade J. 115(12):33(Sept. 17, 1942).

27. Schur, M. O.; Ingalls, E. G. Tech. Assoc. Papers 26:296(1943); Paper Trade J. 117(12):34(1943).

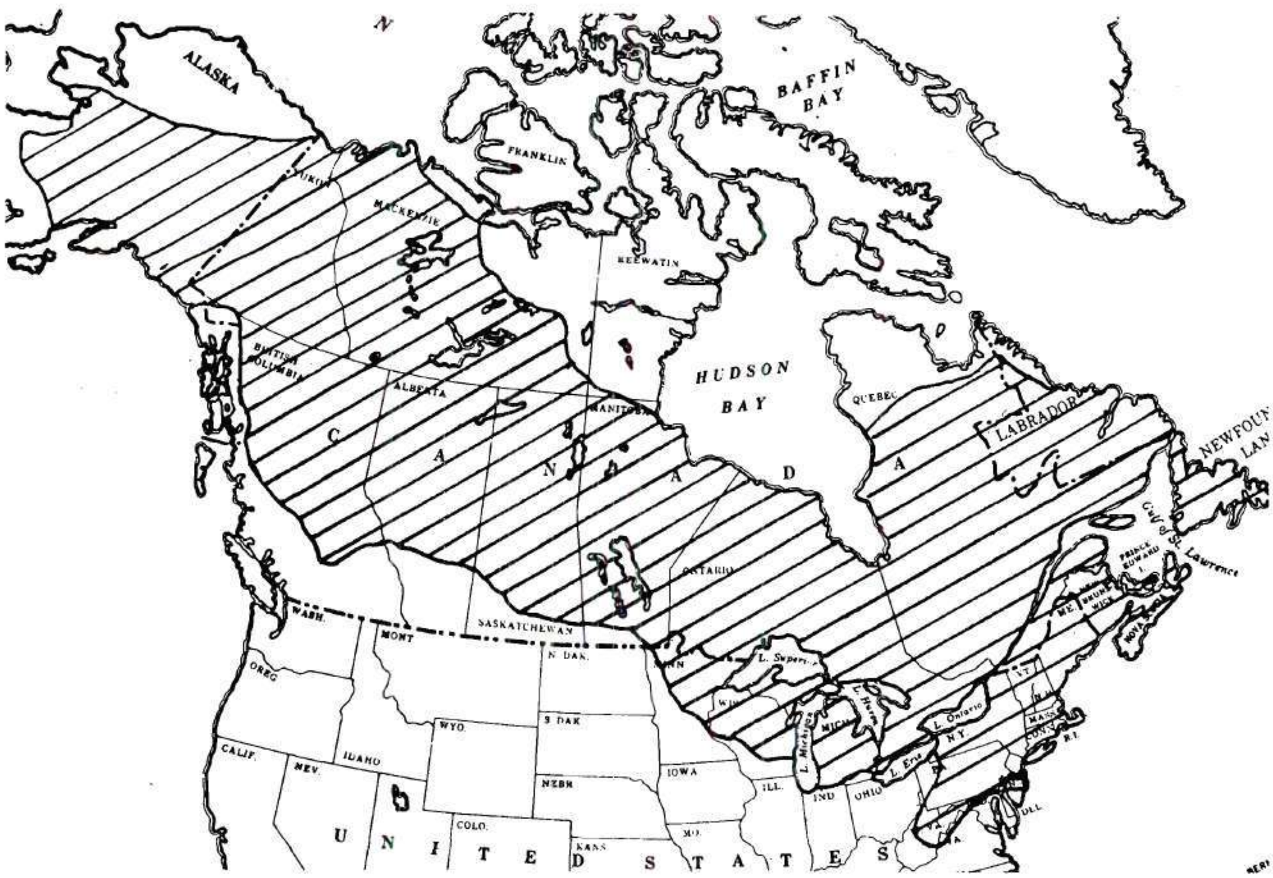
BLACK SPRUCE

Scientific Name *Picea mariana* (Mill.) B.S.P.

Synonyms Bog spruce, swamp spruce, eastern spruce, shortleaf black spruce

Family Name Pinaceae

Range Northern limit of tree growth from Newfoundland to Alaska; northeastern U.S. and Lake States. One of the most abundant conifers in northern North America, the black spruce type occupies about 2 million acres (0.81 million ha) in the Lake States (*1*).



Silvics The tree has a long, straight, tapering bole, an irregularly cylindrical crown, and a shallow spreading root system. In the south it is confined largely to cool sphagnum bogs, muck-filled seepages, and stream courses where it often forms a pure type. Farther north, the pure type is also common on clayey glacial tills and glacio-lacustrine clay plains. The species also grows on loams, sandy loams, and even on sands and gravelly or rocky soils, but there it is usually mixed with other species, such as jack or lodgepole pine. In the north, it makes its best growth on moist, well-drained alluvial bottoms. Swamp-grown trees 200 years old are often only 2-6 inches (5.1-15.2 cm) in diameter. Common associates in various parts of the range are tamarack, balsam fir, white-cedar, black ash, quaking aspen, and white birch. Seed is produced in moderate quantities annually with larger crops at irregular intervals. The chief requisites for germination are a moderate amount of shade and a moist soil, preferably formed from decayed wood and moss. Propagation on wet sites also takes place by "layering:" The lower branches become embedded in the moist sphagnum and sprout roots. The species is rated as tolerant.

Tree Dimensions Small to medium-sized tree; 30-40 ft (9-12 m) tall and 6-12 inches (15-30 cm) in diameter.

Pathology Resistance to decay: low+

The most damaging stem disease of black spruce is the eastern dwarf mistletoe (*Arceuthobium pusillum*). Black spruce is the preferred host for this disease. Several needle rusts infect the species but they are not serious except in Christmas tree plantations. Rots affecting black spruce include *Phaeolus schweinitzii, Stereum sanguinolentum, Armillariella mellea, Phellinus pini* and *F. pinicola* (2).

The species is relatively free of insect attack. It is not a preferred species for attack by the spruce budworm (*Choristoneura fumiferana*). It is occasionally attacked by the eastern spruce beetle (*Dendroctonus piceaperda*), the European spruce sawfly (*Diprion hercyniae*) and the yellow-headed spruce sawfly (*Pikonema alaskensis*). Black spruce is very susceptible to fire damage and windthrow.

Gross Features of the Wood Black spruce wood cannot be separated with certainty from white, red, or Engelmann spruce in gross characteristics or minute anatomy. The wood is lustrous, nearly white to pale yellowish-brown, with an indistinct heartwood. Growth rings are distinct, delineated by the contrast between the narrow, darker latewood and the wider zone of the earlywood of the succeeding ring. A publication on the weight of black spruce stems is Pnevmaticos, *et al.* (3).

Microscopic Structure of the Wood

Tracheids. Average 3.5 mm in length and 25-30 μm in diameter. Weight factor (unbleached kraft) of 0.90. Average cell wall thickness varies from earlywood fibers of less than 1 μm to latewood fibers which measure 3-4 μm. Fegel (4) found root tracheids to average 2.11 mm. The difference in length of tracheids from the pith to the bark is much greater than the difference in length between the mature tracheids at the base and the mechantable top of the stem (5). An additional publication in this area is Ladell (6).

Rays. Uniseriate rays, fine and numerous, are 1-16+ cells in height. Fusiform rays are scattered, with one or rarely two transverse resin canals, and up to 16+ cells in height. Ray tracheids are present in both types of rays and usually restricted to one row on the upper and lower margins.

Resin Canals. Lined with 7-9 thick-walled epithelial cells, resin canals are often occluded with tylosoids in the heartwood. The larger, longitudinal resin canals have a maximum diameter of 135 μm, and the transverse usually less than 30 μm. See additionally the description for red spruce.

Gross Features of the Bark Black spruce bark is characterized by a scaly, almost shaggy appearance without distinct furrows. Grayish-black to brown scales exfoliate easily, sometimes exposing the golden yellow and olive hue of the newly-formed periderm. The gross structure of alternate layers of periderm and secondary phloem in the outer bark are clearly shown on cross section. The narrow inner bark, about 2/32-3/32-inch (0.16-0.24 cm) thick, is light creamy yellow, turning brown after exposure. Sporadic sclereid groups are visible to the naked eye. Comparatively thin, the total bark is generally about 1/4-inch (0.6 cm) thick and seldom over 1/2-inch (1.3 cm) thick. Smith and Kozak (7) found that interior spruce, which included white, black and Engelmann spruce, had a double bark thickness of 6.7% as a percentage of the diameter outside bark for all sections. Additional publications in this area include Hale (8) and Marden, *et al.* (9), and Millikin (10).

Microscopic Structure of the Bark

Young bark. Consists of an epidermis, periderm, cortex and primary and secondary phloem. The epidermis is composed of a single layer of epidermal cells with thickened and cutinized walls beneath which lie a few layers of collenchymatous hypodermis. These cells are long and columnlike with unevenly thick walls, forming irregular intercellular spaces. Directly beneath the hypodermis, periderm appears in one-year-old branches as a few layers of thin-walled phellem cells and a layer of phellogen and phelloderm. Within the cortical region are cortical parenchyma cells and usually about 10-12 vertical resin canals in the very young stem or branch. Traces of primary phloem appear, followed by the secondary phloem, similar in structure to that of mature bark.

Mature bark

Periderm. Composed of one layer of phellogen, 2-3 layers of phelloderm and many layers of phellem. The main part of the periderm is composed of alternate layers of thick and thin-walled cells. The thin-walled cells are rather uniform in shape and size, about 10-25 μm on radial dimension, with uniformly thick, suberized walls about 2 μm thick. The thick-walled cells, more variable in size and wall thickness, have lignified walls often more than 10 μm thick. A periderm in the rhytidome may consist of 3-5 alternate bands of 5-10 layers of each type of phellem cell. The outer bark is different from the inner bark by the additional development of periderm and more lignified cells with increased cell contents.

Sieve Cells. Regularly aligned in radial rows and interrupted by tangential lines of parenchyma and sclereids, and phloem rays and resin canals. Sieve cells in the inner bark vary in length from 1.42 mm-4.38 mm, averaging about 3.32 mm, and are gradually pointed at both ends. In cross section, sieve cells appear rectangular in shape, usually 20 μm in radial dimension and 40 μm in tangential dimension with uniformly thick walls, about 2 μm thick. In the outer bark, the sieve cells are mostly deformed and generally much shorter. Sieve cells amount to approximately 75% of the tissue elements of the secondary phloem (*11*).

Parenchyma. About the same size and shape as the sieve cells on cross section, but with a slightly expanded radial dimension, parenchyma are aligned in tangential lines, usually one cell thick. Individual cells, usually about 150 μm high, form strands about the same length as the adjacent sieve cells. Parenchyma cells often contain abundant "tanniferous" substances and single calcium oxalate crystals about 10 μm in diameter.

Sclereids. Originating from the parenchyma, sclereids aggregate in small groups aligned more or less in discontinuous tangential lines. The individual cells are irregular in shape and branched with very thick walls. Laminate layers on the secondary walls and simple pits are distinct. The size of the sclereid groups vary but, in general, the radial dimension may be up to 150 μm, tangential, up to 1 mm, and height, 1-2 mm.

Rays. Phloem rays are both uniseriate and fusiform. Uniseriate rays are generally 10-15 cells or 100-200 μm high. Albuminous cells are in almost every ray close to the cambial zone. Fusiform rays containing horizontal resin canals lined with thin-walled epithelial cells are common.

Compared with species of white, red, and Sitka spruce, the bark of black spruce is distinguished by its olive green to bright yellow-colored periderm, the number of sieve cells between two parenchyma lines, and the rather constant amount of sclereids in both the inner and outer bark.

According to Brudermann and Koran (*12*), sieve cells measured 4 mm in length and 30 μm in diameter and constituted 52% of the volume of the inner bark. Sieve cell volume decreased gradually from 63% at the cambium to 39% at the outer dead phloem as a result of the collapse of these elements. In contrast, the volume of longitudinal parenchyma increased from 29% to 44%. Sclereids made up 3% of the inner bark by volume and this increased to 10% in the outer bark.

Physical Properties of Wood

Specific gravity	Green volume	0.40
	Air-dry volume	0.43
	Oven-dry volume	0.45
Density, lb/cu ft (kg/cu m)	Green	35 (561)
	Air-dry	30 (481)
	Oven-dry	28 (448)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	25 (400)

Percent shrinkage, dried to 0% moisture content: r – 4.1, t – 6.8, v – 11.3

Percent moisture content, when green

Green basis	28
Oven-dry basis	38

Additional information in this area includes Bendtsen (*13*), Besley (*14*), Carmichael (*15*), Maeglin (*16*), Marden (*9*), Pronin (*17*), and Wahlgren, *et al.* (*18,19*).

Physical Properties of Bark

Specific gravity green volume	Inner bark	0.33
	Outer bark	0.46
	Total bark	0.42
Density (100% moisture content)	Green weight/green volume	0.97
Specific gravity oven-dry weight & volume (*20*)		0.60

An additional publication in this area is Lamb and Marden (*21*).

A bibliography on black spruce has been published by Shoup and Nairn (*22*).

Chemical Composition of Wood

Proximate Analyses

	Cundy (*23*)	Wise and Ratliff (*24*)[a] Series A	Wise and Ratliff (*24*)[a] Series B	Clermont and Schwartz (*25*)
Lignin, %	27.3	28.0	28.0	27.25[b]
Holocellulose, %	–	–	–	71.7[c]
C. & B. cellulose, %	57.2	–	–	–
Alpha-cellulose, %	45.8	51.5	45.6[d]	51.50[e]
Hemicellulose, %	–	–	–	15.18[b]
Ash, %	0.29	0.36	0.36	0.21
Pentosans, %	12.5	–	–	7.56
Mannan, %	8.5	–	8.0	–
Acetyl, %	1.16	1.12	1.12	1.14
Methoxyl, %	4.65	–	–	5.07
Xylan (cor. for uronic anhydride), %	–	–	10.50	–
CH_2 (from MeO not in lignin), %	–	–	0.22	–
Moisture content, %	–	–	–	7.67
Solubility in				
Ethyl ether	–	–	–	1.03
1% NaOH	–	–	–	12.3
Hot water	2.1	–	–	2.46
Cold water	–	–	–	1.41
Alcohol-benzene, %	2.2	–	–	–
Polyuronides (as CO_2), %	0.86	–	–	–
Uronic anhydride, %	–	–	4.1	3.67
In hemicelluloses				
Pentosans	–	–	–	36.3[f]
Uronic anhydride	–	–	–	16.7[f]
Hexosans (by difference)	–	–	–	47.0[f]

[a]Extractive-free wood.
[b]Corrected for ash.
[c]Corrected for ash, lignin and extractives.
[d]Corrected.
[e]Corrected for ash and lignin.
[f]As % of moisture-free hemicelluloses.

Browning and Isenberg (*26*) found the alcohol-benzene content to be 0.6% and ether-solubles, 0.2%. The Institute of Paper Chemistry, Project 3212, Report 8, found alcohol-benzene extractives to be 1.5%. Small amounts of pectic substances have been isolated (*27*).

The distribution of mannans over the various hemicellulose fractions was studied. The fraction most readily extracted by alkali contained the lowest percentage of mannan, whereas the least soluble fraction showed the highest mannan content. Over half the mannose units, however, were retained in the resistant alpha-cellulose residue. Total mannan in the wood was 10.3% (*24*).

Carbohydrates. For information on glucomannans, see Dutton and Walker (*28*).

Extractives. Successive extractions: water, 3.28%; ether, 0.63%; alcohol, 0.96%; total, 4.87% (*29*).

Arabogalactan (0.1-0.2%) has been found in the water extract. It contains 13.2% uronic anhydride, 65.3% galactan, and 11.5% araban. The acetate is insoluble in water and common organic solvents; glucose, xylose, and mannose are absent (*30*).

Native lignin (2-3%) was obtained by alcohol extraction. The behavior of this extractive on methylation and acetylation has been described (*31*).

Conidendrin has been found in the branches of young trees (*32*).

Ether extractives (0.8%) contain 20.9% unsaponifiable matter, 38.7% unsaturated fatty acids, 2.6% saturated fatty acids, and 30.7% resin acids. The unsaponifiable material contains a large amount of a phytosterol (probably identical with 22,23-dihydrostigmasterol) (*33*).

The wood contains the extractive liovil (*34*).

For information on extractives see Kleinert (*35*).

For the percent composition of extractives see Drew and Pylant (*36*).

Other Information. Musha and Goring (*37*) found the klason lignin content to be 0.284% and the acid-soluble lignin content to be 0.003%.

Chemical Composition of Bark

Proximate Analyses

	The Institute of Paper Chemistry, Project 3212, Report 8	Chang and Mitchell (*38*)	Richter (*39*)	
Lignin, %	–	–	45.84	40.20
Ash, %	3.1	2.0	–	2.1
Pentosans, %	–	–	8.84	9.5
Methoxyl, %	–	3.20	–	–
Solubility in				
Alcohol-benzene, %	14.7	–	–	–
Alcohol, %	–	14.6	–	–
Benzene, %	–	5.0	–	–
Ether, %	–	–	2.26	4.10
1% NaOH, %	–	28.0	–	–
Hot water, %	–	4.4	10.46	12.8
Acid-alcohol, %	–	–	12.06	4.10

Carbohydrates. For reducing sugars from extractive-free bark, see Chang and Mitchell (*38*).

Other Information. The bark contains 0.8% calcium, 0.1% silica (IPC, Project 3212, Report 8), 74.7% volatiles, and 22.5% fixed carbon (Millikin, *10*); for elemental analysis see Millikin (*10*) and Harder and Einspahr (*40*).

Pulping

Acid Sulfite. Treatment with NaOH and HCHO prior to acid sulfite pulping makes pulps suitable for glassine paper.

Ammonium sulfide. The pulps are easily bleached to good brightness and have mechanical properties equal to or better than kraft pulps of similar yield.

Kraft. The wood is readily reduced, yield is normal, and pulp is strong and of fine texture; it is used for high-grade wrapping papers and fiberboard (*41-44*). The pulp is used for paper with high burst and tensile strength and adequate tear strength. It is also used for coated publication papers, fine papers, glassine and greaseproof papers tissue papers (toilet and facial), lightweight offset papers, wallpapers, and specialty papers. For kraft pulping information see Hatton and Keays (*45*).

Mechanical. The wood is readily reduced. On a cord basis, the yield is highest of the eastern spruces. The pulp has excellent color and standard strength. It requires power of 60-80 HP-days/ton (*44,46,47*).

Neutral sulfite semichemical. For information see Chidester (*48*) and McGovern and Keller (*49*).

Oxygen. The yield from oxygen pulping is higher than from kraft; sodium borate or NaOH is included in the liquor. Addition of KI improves strength (*50*).

Sulfite. The wood is reduced readily, yield is normal, and pulp is strong and of excellent color. It may be somewhat specky due to a large number of small black knots with accompanying ingrown bark; the specks are readily bleached. It is used for newsprint, wrapping papers, book papers, high-grade printing paper, and bond paper (*44,49,51-55*). Fluffed wood pulp is made from low-yield bleached sulfite pulps (*56*).

Other pulping methods. Black spruce has also been pulped by alkaline sulfite (*57*), organosolv [For pulp properties of pulps made with ethanol-water see Kleinert (*58*)], soda (*59*), soda-amine (These pulps are generally better than soda pulps and not so good as kraft pulps except in tear strength.), and thermomechanical [For pulp properties see Sinkey (*60*).] methods; chlorine dioxide, performic acid, peracetic acid, and perpropionic acid gave pulp of high yield and good strength (*61*).

Utilization of Wood and Bark

Use properties of wood. The wood is lightweight and has good strength for its weight. It does not impart odor or color. It is somewhat heavier, stronger, harder, and more durable than white spruce. It is a very valuable pulpwood.

Calorific Value of Wood

Million of BTU/air-dry cord	19.1
Million kg cal/air-dry cord	4.8

Calorific Value of Bark

K cal/kg	4581
BTU/ft^3	225,582
kg cal/cu m	1608
BTU/oven-dry lb	8610
kg cal/oven-dry kg	4784

Chemical uses of wood. In New England an oil is prepared by the steam distillation of the needles and twigs of black spruce. This oil is used as a perfume in greases and shoe blackings and in liniments and other medicinal preparations.

Spruce gum is collected from trees after three years of aging and is used in chewing gum and in medicinal preparations.

Other uses of wood. It is used for mine timbers and similar applications. Like other softwoods, spruce may contain compression wood. Some wood is used for boxes and crates, light and medium construction, sounding boards, ladder rails, canoe paddles, oars, and scaffolding.

Other uses of bark. Bark is mixed with *Abies balsamea* bark and used for hardboards and insulation boards.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 445, 1973, 114 p.
2. USDA, Forest Service. Agriculture Handbook No. 271, 1965, 762 p.
3. Pnevmaticos, S. M.; Jaeger, T. A.; Perem, E. Can. J. For. Res. 2(4):427-33(1972).
4. Fegel, A. C. N.Y. State Coll. For., Tech. Bull. No. 55, 1941, 20 p.
5. Hall, A. D. Ontario Dept. of Lands & Forests, Res. Rept. (Forestry) No. 49, 1963, 23 p.
6. Ladell, J. L. Ontario Res. Foundation, 1971, 34 p. + tables and figures.
7. Smith, J. H. G.; Kozak, A. Mimeo of "Thickness and percentage of bark of the commercial trees of British Columbia," University of British Columbia, Faculty of Forestry, 1967.
8. Hale, J. D. Pulp Paper Mag. Can. 56(13):113-17(1955).
9. Marden, R. M.; Lothner, D. C.; Kallio, E. USDA, Forest Serv. Res. Pap. NC-114, 1975, 9 p.
10. Millikin, D. E. Pulp Paper Mag. Can. 56(13):106-8(1955).
11. Chang, Y. P. TAPPI Monograph Series No. 14, 1954. 249 p.
12. Brudermann, G.; Koran, Z. Can. J. Bot. 51(9):1649-53(1973).
13. Bendtsen, B. A. USDA, Forest Serv. Res. Pap. FPL-237, 1974, 28 p.
14. Besley, L. Pulp Paper Res. Inst. Can. Tech. Rept. No. 489 (Woodlands Res. Index No. 182), 1966, 30 p.
15. Carmichael, A. J. *In* Proc. 11th Meeting of Committee on Forest Tree Breeding in Canada, MacDonald College, Que., August 8-10, 1968, p. 223-5.
16. Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-202, 1973, 40 p.
17. Pronin, D. USDA, Forest Serv. Res. Pap. FPL-161, 1971, 16 p.

18. Wahlgren, H. E.; Hart, A. C.; Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-61, 1966, 22 p.

19. Wahlgren, H. E.; Baker, G.; Maeglin, R. R.; Hart, A. C. USDA, Forest Serv. Res. Pap. FPL-95, 1968, 12 p.

20. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.

21. Lamb, F. M.; Marden, R. M. Forest Prod. J. 18(9):77-83(1968).

22. Shoup, J. M.; Nairn, L. D. Liais. Serv. Note. For. Res. Lab., Winnipeg, No. MS-L-6, 1969, 72 p.

23. Cundy, P. F. Paper Ind. 26:170(1944).

24. Wise, L. E.; Ratliff, E. K. Arch. Biochem. 19:292(1948).

25. Clermont, L. P.; Schwartz, J. Pulp Paper Mag. Can. 52(13):103-5(Dec., 1951).

26. Browning, B. L.; Isenberg, I. H., *In* Wise, L. E. and Jahn, E. C., eds., Wood Chemistry. New York: Reinhold. p. 1264. 1952.

27. Anderson, E. J. Biol. Chem. 165:233(1946).

28. Dutton, G. G. S.; Walker, R. H. Cellulose Chem. Technol. 6(3):295-305(May/June, 1972).

29. Lewis, H. F. Tappi 33:299(1950).

30. Brauns, F. E. Science 102:155(1945).

31. Brauns, F. E. J. Am. Chem. Soc. 61:2120(1939).

32. Erdtman, H. Svensk Papperstidn. 47:155(1944).

33. Wise, L. E.; Moore, S. T. J. Org. Chem. 10:516(1945).

34. Barton, G. M. Wood Fiber 2(2):144-50(Summer, 1970).

35. Kleinert, T. N. Tappi 57(8):99-102(Aug., 1974).

36. Drew, J.; Pylant, G. D., Jr. Tappi 49(10):430-8 (Oct., 1966).

37. Musha, Y.; Goring, D. A. I. Wood Sci. 7(2):133-4(Oct., 1974).

38. Chang, Y.-P.; Mitchell, R. L. Tappi 38(5):315-20(May, 1955).

39. Richter, G. A. Ind. Eng. Chem. 33(4):532-8(1941).

40. Harder, M. L.; Einspahr, D. W. To be submitted to Tappi.

41. Hart, J. S.; Strapp, R. K. Pulp Paper Mag. Can. 49(3):151(Feb., 1948).

42. Holzer, W. F.; Booth, K. G. Tappi 33:95(1950).

43. McGovern, J. N.; Keller, E. L. Pulp Paper Mag. Can. 49(9):93(1948).

44. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485. May, 1927. 101 p.

45. Hatton, J. V.; Keays, J. L. Pulp Paper Mag. Can. 74(1):79-87(T11-19) (Jan., 1973).

46. Pillow, M. Y.; Schafer, E. R.; Pew, J. C. Tech. Assoc. Papers 19:178(1936); Paper Trade J. 102(16):36(April 16, 1936).

47. Wynne-Roberts, R. I. Tech. Assoc. Papers 20:258(1937); Paper Trade J. 104(6):46(Feb. 11, 1937).

48. Chidester, G. H. Proc. Forest Products Research Soc. 3:197(1949).

49. McGovern, J. N.; Keller, E. L. Pulp Paper Mag. Can. 49(9):93(1948).

50. Minor, J. L.; Sanyer, N. Tappi 57(5):120-2(May, 1974).

51. Baum, M.; Bard, J. W.; Salvesen, J. R.; Brabender, G. J. Tech. Assoc. Papers 30:405(1947); Paper Trade J. 124(9):130(1948).

52. Holzer, W. F.; Booth, K. G. Tappi 33:95(1950).

53. Johnsen, B.; Reese, C. H. Tech. Assoc. Papers 14:326(1931); Paper Trade J. 91(11):66(Sept. 11, 1930).

54. Johnsen, B.; Reese, C. H. Tech. Assoc. Papers 16:326(1933); Paper Trade J. 97(1):36(July 6, 1933).

55. McGovern, J. N. Tappi 33:486(1950).

56. Aberson, G. M. TAPPI STAP No. 8:282-305; discn:305-7(May, 1969); publ. 1970.

57. Ingruber, O. V.; Allard, G. A. TAPPI/CPPA Intern. Sulfite Pulping Recovery Conf. (Boston), Oct.-Nov. 1972:331-62.

58. Kleinert, T. N. Tappi 57(8):99-102(Aug., 1974).

59. Ross, J. H. Pulp Paper Mag. Can. 29:482(1930).

60. Sinkey, J. D. CPPA Ann. Mtg. (Montreal) Preprints 64A:21-8(Jan. 31-Feb. 3, 1978).

61. Thompson, N. S.; Kaustinen, O. A. Can. pat. 806,573. Issued Feb. 18, 1969.

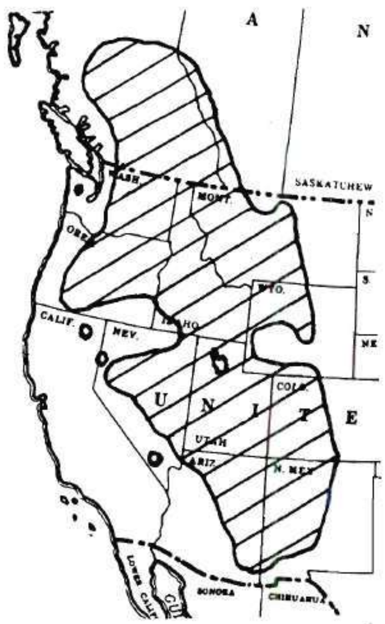
ENGELMANN SPRUCE

Scientific Name *Picea engelmannii* Parry

Synonyms Columbian spruce, mountain spruce, silver spruce, white spruce

Family Name Pinaceae

Range Widely distributed species; extensive stands in nine western states and two Canadian provinces. The range extends from British Columbia and Alberta south to New Mexico and Arizona and covers nearly 10 million acres (4.0 million ha) in the Rocky Mountains. It is found at 1500-12,000 ft (460-3660 m) in the northern part of its range, 9000-11,000 ft (2740-3350 m) in the central Rockies, and 10,000-12,000 ft (3000-3660 m) in the southern Rockies.



Silvics In dense stands, Engelmann spruce has a straight, clean trunk with a close, very short, narrowly pyramidal crown of small branches, and a shallow but well-developed root system. The rate of growth varies from extremely slow, under the very adverse conditions close to the timberline, to fairly rapid under favorable conditions, especially in the northern part of its range. It reaches its best development on deep, rich, loamy soils of high moisture content. Pure stands of considerable extent are common, although the tree occurs abundantly in mixture with other conifers. Subalpine fir is its common associate at all elevations. At lower altitudes, it is often associated with grand, silver, and white firs, Douglas-fir, western larch, western hemlock, western red-cedar, lodgepole and western white pine, blue spruce, and aspen. At higher altitudes, the chief associates are mountain hemlock, subalpine larch, whitebark, limber and bristlecone pines, and corkbark fir. Engelmann spruce occasionally shares new burns with lodgepole pine but is usually the less aggressive species. Good seed crops are generally borne every 2-6 years with light crops in more than half of the intervening years. The early growth of the seedlings is slow. The species is rated as tolerant but is less so than subalpine fir, its most common associate throughout much of its range.

Tree Dimensions 80-100 ft (24-30 m) tall and 18-30 inches (46-76 cm) in diameter.

Pathology Resistance to heartwood decay: slightly or nonresistant.

Because of its thin bark and persistent branching habit, Engelmann spruce is especially susceptible to destruction or injury by fire. Most trunk and root rots in old-growth stands appear to be associated with fire injury (*1*). The most common diseases of Engelmann spruce are caused by wood-rotting fungi, including *Phellinus pini, Polyporus circinatus, Coniophora cerebella, Peniophora luna,* and *Stereum sanguinolentum* (*2*). Two other rots, closely linked with windthrow, are *Fomes pinicola* and *C. puteana* (*3*).

Although the spruce beetle (*Dendroctonus rufipennis*) is usually present in small numbers, occasional sporadic outbreaks kill extensive stands of spruce. During these epidemics, trees of all ages and sizes are killed, although preference is shown for trees of larger diameter (*4*). The spruce budworms (*Choristoneura fumiferana* and *C. occidentalis*) are the other serious pests of Engelmann spruce, feeding principally on buds and foliage of the current year.

Gross Features of the Wood The wood is nearly white to pale yellowish-brown with an indistinct heartwood. It is generally straight grained, medium to fine textured, and without characteristic odor or taste. It is light to moderately light in weight, soft, low in shock resistance and with moderately small shrinkage. Growth rings are distinct, delineated by a usually wide earlywood zone with a gradual transition to a generally narrow, darker latewood. In some samples of Engelmann spruce the transition from springwood to summerwood is more abrupt than in eastern spruce and the summerwood is then usually appreciably denser than the springwood. The wood of the eastern spruces is also usually slightly heavier and stronger than that of Engelmann spruce.

Resin ducts in Engelmann spruce, visible as white specks in the latewood, are few in number but distinguish the wood of Engelmann spruce from white fir and other western true firs.

Microscopic Structure of the Wood

Tracheids. Average 3.0 mm in length and 25-30 μm in diameter. Cell wall thickness averages 2.9 μm. Weight factor (unbleached kraft) 0.90.

Resin Canals. Transverse resin canals have diameters of usually less than 30 μm and the longitudinal canals average 50-90 μm. The ducts, lined with 7-9 thick-walled epithelial cells, have occasional tylosoids in the heartwood.

Rays. Two types with nondentate ray tracheids present in both. Uniseriate rays, 1-16+ cells in height, are numerous. Biseriate rays are rare. Fusiform rays, scattered with one or rarely two resin canals, are 2- to 3-seriate through the central thickened portion, tapering to uniseriate and about the same height.

Longitudinal parenchyma. Lacking.

See additionally the description for red spruce.

Gross Features of the Bark The bark of Engelmann spruce is very thin and rough with dull, reddish-brown, loosely attached scales. The total thickness of the bark on mature trees is about 0.3 inch (0.76 cm). The inner bark, comparatively light in color, is about 0.18 inch (0.46 cm) thick. Articles by Smith and Kozak (5) and Myers and Alexander (6) give additional information on thickness and percentage of bark.

Microscopic Structure of the Bark

Young trees or branches. The epidermis consists of cutinized epidermal cells, uniseriate multicellular hairs, and at the concave portions, small groups of collenchyma cells formed from the hypodermis beneath. The periderm, with thin-walled and enlarged phellem cells, originates from the outer margin of the cortex. Cortex parenchyma, resin cells, sclereids, and vertical resin canals comprise the rather broad cortex. The secondary phloem has the same basic cell pattern arrangement as in the mature tree.

Mature trees

Periderm. New periderm develops rather often, producing the narrow layers of rhytidome. The periderm is composed of 2-6 layers of phelloderm, a layer of phellogen and usually 2-4 layers of uniform, thin-walled and suberized phellem cells. The cells are regularly aligned and rectangular or nearly square in shape, about 30 μm in diameter on cross section and 40-70 μm high on tangential section. Phelloderm cells are parenchymatous in nature, often becoming "lignified" and thick walled, and at times alternating with the thin-walled phellem cells. Resinous substances and crystals are often found in the periderm cells.

Phloem fibers. None

Sclereids. The inner bark of Engelmann spruce, unlike other spruces, seldom develops sclereids. However, small groups of thick-walled, branched and twisted cells are sporadically distributed in the outer bark.

Sieve Cells. Aligned in radial rows and interrupted by parenchyma about every 5-7 cells. They vary in length from 2.1-4.4 mm and comprise 78% of the tissue elements of the secondary phloem.

Parenchyma. Tangentially aligned in more or less continuous rows, newly differentiated parenchyma are about the same size and shape as sieve cells on cross section but expand quickly after a few seasons' growth. Individual cells containing abundant tanniferous substances, starch and crystals, are about 100-150 μm in height. Parenchyma strands are usually about the same length as adjacent sieve cells and comprise approximately 15% of the tissue elements of the secondary phloem.

Rays. Uniseriate rays are usually 14 cells or about 250 μm high and sometimes up to 400 μm high. Erect marginal cells or albuminous cells are conspicuous in every ray close to the cambial zone. Fusiform rays contain the resin canals with thin-walled epithelial cells lining the ducts. Rays comprise approximately 7% of the tissue elements of the secondary phloem.

Physical Properties of Wood

Specific gravity	Green volume	0.31
	Air-dry volume	0.33
	Oven-dry volume	0.35
Density, lb/cu ft (kg/cu m)	Green	39 (620)
	Air-dry	23 (370)
	Oven-dry	22 (350)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	20 (320)

Overall increase in specific gravity with increase in height of tree (*7*).

Percent shrinkage, dried to 0% moisture content (*8*): r – 3.4, t – 6.6, v – 10.4.

Percent moisture content, when green	
Green basis	50
Oven-dry basis	100

Percent moisture content oven-dry basis (*8*)	
Heartwood	51
Sapwood	173

Additional information in this area includes Bendtsen and Wahlgren (*9*). Maeglin and Wahlgren (*10*), and Markstrom and Hann (*11*).

Physical Properties of Bark

Specific gravity green volume	Inner bark	0.41
	Outer bark	0.52
	Total bark	0.51
Density (100% moisture content)	Green weight/ green volume	1.14
Specific gravity oven-dry weight & volume (*12*)		0.80
Percent moisture content oven-dry basis (*13*)	Inner bark	121
	Outer bark	60

A general bibliography on Engelmann spruce has been compiled by Christensen and Hunt (*14*).

Chemical Composition of Wood

Proximate Analyses

	F.P.L. (*15*)
Lignin, %	26.3
Holocellulose, %	67.9
Alpha-cellulose, %	44.3
Ash, %	0.2
Pentosans	
Total, %	9.2
In cellulose, %	8.2
Solubility in	
Alcohol-benzene, %	2.8
Ether, %	1.4
1% NaOH, %	12.2
Hot water, %	3.7

The Institute of Paper Chemistry, Project 3212, Report 5, found alcohol-benzene extractives to be 2.8%.

Extractives

Conidendrin has been found in branches of young trees (*16*). For information on extractives see Drew and Pylant (*17*).

Chemical Composition of Bark

Proximate Analyses

	The Institute of Paper Chemistry Project 3212 Report 5	Chang and Mitchell (*19*)
Ash, %	2.6	2.5
Methoxyl, %		2.90
Soluble in		
Alcohol-benzene, %	24.4	
Benzene, %		5.2
95% Alcohol, %		25.9
1% NaOH, %		22.2
Caclium, %	0.8	
Silica, %	0.08	

For information on elements in bark, see Harder and Einspahr (*19*).

Pulping

Kraft. The wood is readily reduced, yield is normal, and the pulp is strong with unusually high initial burst strength (*20,21*). It can be bleached to 91% brightness. Kraft pulps produce strong papers of fine texture.

Mechanical. The wood is readily reduced, the yield is 92%, it is of excellent color and standard strength, it requires power similar to that of white spruce, it is used for all furnishes requiring mechanical pulp (*21,22*).

NSSC. For data on pulp strength, see McGovern and Keller (*23*).

Sulfite. The wood is readily reduced, the yield is normal, and the pulp is strong and of fine texture and excellent color, it is easily bleached, it is used for newspapers, wrapping papers, book papers, high-grade printing papers, and bond papers (*22*). It makes good viscose-grade sulfite pulp. The pulp is suitable for making newsprint, wrapping paper, book papers, high-grade printing papers, and bond papers.

Other information. The wood has excellent pulp and papermaking properties, ranking with the eastern spruces (white, red, and black). The long fibers are of relatively light color, and resin is absent. NSSC pulps contain 0.2%

lignin, 97.7% C. & B. cellulose, 84.6% α cellulose, and 9.6% pentosans (*23*).

Utilization of Wood and Bark

Use properties. Medium to fine texture, moderately small shrinkage. The wood is low in beam and post strength and in its ability to resist shock. It can be used on some construction where moderate strength is required. It has good nail-holding properties, is moderately limber, and is soft. If sufficient time is allowed, the lumber can be kiln-dried without difficulty. It is easily glued under a wide range of gluing conditions. It is not decay resistant.

Calorific Value of Wood

Million of BTU/air-dry cord	17.6
Million of kg cal/air-dry cord	4.4

Calorific Value of Bark

BTU/lb	8359
kg cal/kg	4644

280,794 BTU/ft^3

Other uses of wood. The principal use is for home construction. Rotary-cut veneer is used for plywood. It is also used for mine timbers, poles, ties, fuel.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 271, 1965, 762 p.
2. Hornibrook, E. M. J. Forestry 48:408-17(1950).
3. Rocky Mountain Forest & Range Experiment Station. U.S.F.S., Mimeo, 1956, 86 p.
4. Furniss, R. L.; Carolin, V. M. USDA, Forest Serv. Misc. Publ. No. 1339, 1977, 654 p.
5. Smith, J. H. G.; Kozak, A. Mimeo of "Thickness and percentage of bark of the commercial trees of British Columbia," University of British Columbia, Faculty of Forestry, 1967.
6. Myers, C. A.; Alexander, R. R. Bark thickness and past diameters of Engelmann spruce in Colorado and Wyoming. USDA, Forest Serv. Res. Note RM-217, 1972, 2 p.
7. Okkonen, E. A.; Wahlgren, H. E.; Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).
8. U.S. Forest Products Lab. Agriculture Handbook No. 72, 1974.
9. Bendtsen, B. A.; Wahlgren, H. E. USDA, Forest Serv. Res. Pap. No. FPL-128, 1970.
10. Maeglin, R. R.; Wahlgren, H. E. USDA, Forest Serv. Res. Pap. No. FPL-183, 1972.
11. Markstrom, D. C.; Hann, R. A. USDA, Forest Serv. Res. Note RM-212, 1972.
12. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969.
13. Smith, J. H. G.; Kozak, A. Forest Prod. J. 21(2):38-40(1971).
14. Christensen, E. M.; Hunt, M. J. USDA, Forest Serv. Res. Paper INT-19, 1965.
15. Forest Products Laboratory. Unpublished data.
16. Erdtman, H. Svensk Papperstidn. 47:155(1944).
17. Drew, J.; Pylant, G. D., Jr. Tappi 49(10):430-8 (Oct., 1966).
18. Chang, Y.-P.; Mitchell, R. L. Tappi 38(5):315-20(May, 1955).
19. Harder, M. L.; Einspahr, D. W. To be submitted to Tappi.
20. Bray, M. W.; Singer, B. Tech. Assoc. Papers 30:325(1947); Paper Trade J. 125(8):49(Aug. 21, 1947).
21. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485. May, 1927. 101 p.
22. Thickens, J. H.; McNaughton, G. C. USDA, Bull. No. 343. 1916.
23. McGovern, J. N.; Keller, E. L. Pulp Paper Mag. Can. 49(9):93(Aug., 1948).

SITKA SPRUCE

Scientific Name *Picea sitchensis* (Bong.) Carr.

Synonyms Coast spruce, tideland spruce, yellow spruce, tidewater spruce

Family Name Pinaceae

Range A narrow belt, over 1800 miles (2900 km) long, from Cook's Inlet, Alaska, south along the coast and on nearby islands to Mendocino County, California. The portion within the United States totals about 10 million acres (4.0 million ha) (*1*). Commercial operations are confined from sea level to 1200 ft (366 m), although the tree is found at elevations up to 3000 ft (915 m). Maximum development is reached on the Olympic Peninsula of Washington and the Queen Charlotte Islands of British Columbia.

Silvics The tree has a long, clear, cylindrical bole, a short, rather open crown, and a very shallow, wide-spreading root system. In mature trees the bases are commonly heavily buttressed. This species forms extensive pure forests in certain sections and in others occurs in mixture with both softwoods and hardwoods. In Alaska its chief associate is western hemlock, whereas in British Columbia, Washington, and northwestern Oregon, it often mingles with Douglas-fir, western red-cedar, silver and grand fir, red alder, bigleaf maple, and black cottonwood; in southwestern Oregon and northwestern California it is occasionally found with Port-Orford-cedar and redwood. Large quantities of seed with a high rate of germination and persistent vitality are produced at three- or four-year intervals. Best growth occurs on deep loam soils with high moisture content. Sitka spruce is rated as tolerant, less tolerant than western hemlock and western red-cedar but more tolerant than Douglas-fir.

Tree Dimensions The largest native spruce, 180-200 ft (55-61 m) tall and 3.5-4.5 ft (107-137 cm) in diameter.

Pathology Resistance to decay: low+

Sitka spruce is very susceptible to decay following injury (*2*). The most common rot organism infecting Sitka spruce is the red belt fungus (*Fomes pinicola*). Other trunk rots include *Phellinus pini, Lentinus kaufmanii* and *Phaeolus schweinitzii.*

The most serious insect affecting Sitka spruce reproduction is the white pine weevil (*Pissodes strobi*). It kills or seriously injures terminal shoots of trees up to 50 ft (15 m) tall. The spruce aphid (*Elatobium abietinum*) feeds almost exclusively on spruce. The spruce beetle (*Dendroctonus obesus*) is normally present in small numbers with occasional, sporadic outbreaks killing extensive stands.

Gross Features of the Wood The wood of Sitka spruce can be separated from that of other spruces because of the color of the heartwood. The sapwood is creamy white to light yellow, whereas the heartwood is light pinkish yellow to pale brown with a purplish cast, darkening on exposure to silvery brown with a faint tinge of red. The wood is moderately soft, somewhat lustrous, even and generally straight grained, medium textured, nonresinous, without characteristic taste or odor. Flat grain boards exhibit a distinct but not conspicuous growth ring. The earlywood zone is usually one to two times the width of the latewood. In the x-section the rays are very fine and are not visible with the unaided eye except where they include a horizontal resin canal. In the radial surface they are darker than the background and form a fine, rather conspicuous fleck. Both longitudinal and horizontal resin canals are normally present. The longitudinal canals are fairly large, appearing as white flecks in the dark heartwood with the unaided eye, sparse to fairly numerous, solitary or 2 to several contiguous tangentially, and irregularly distributed. The horizontal canals are smaller than the longitudinal ones but are visible against the dark background of heartwood as whitish rays. Longitudinal parenchyma cells are absent. The split tangential surface often shows a dimpling effect. Additional information in this area includes Dinwoodie (*3*).

Microscopic Structure of the Wood

Tracheids. Average 5.6 mm (3.6-7.3 mm) in length and 35-45 μm in diameter. Summerwood tracheids averaged 12% longer than springwood tracheids (*4*). Coarseness of the earlywood and latewood of holo- and alpha-cellulose pulps determined by Sastry and Wellwood (*5*). Additional coarseness information in Britt (*6*). Bordered pits are in 1-2 rows on the radial walls; tangential pitting in the last few rows of latewood tracheids; pits leading to ray parenchyma small, uniform in size (piceoid), with distinct border, 1-4 (generally 2-3) per cross-field; ray tracheid pits present. Volume occupied, approximately 92%. Additional information on tracheid length can be found in Elliott (*7*).

Resin Canals. Longitudinal, average, 60-90 μm in diameter; horizontal, less than 35 μm; thick-walled epithelial cells, occasional tylosoids. Volume occupied, <1%.

Rays. Two types, uniseriate and fusiform; the uniseriate rays are numerous, 1-53 cells (944 μm) in height; the fusiform rays are scattered, with a horizontal resin canal, 3- to 5-seriate in the central portion, tapering to uniseriate margins, up to 60 cells (1060 μm) high; ray tracheids are present in both types of rays, usually restricted to one row on the upper and lower margins, with nondentate inner walls. Ray parenchyma in the heartwood generally with gummy infiltration. Five rays per mm tangentially on x-section and 20 rays per square mm on t-section. Volume occupied, approximately 7%.

Longitudinal parenchyma. Absent.

Gross Features of the Bark Thin (usually less than one-half inch thick), broken into thin, elliptical, concave, loosely appressed, silvery-gray to purplish-gray scales. Average percent double bark thickness at breast height, based on 39 trees, was 2.9% (*8*).

Microscopic Structure of the Bark (*9*)

Periderm. Composed of both very thick- and thin-walled cells.

Phloem Fibers. None.

Sclereids. Occur in small groups with the groups rather sporadic and sometimes absent in the inner bark of comparatively young trees. Sitka spruce has more sclereid groups than any other species observed.

Rays. Fusiform rays with horizontal resin canals are always present.

Physical Properties of Wood

Specific gravity	Green volume	0.37
	Air-dry volume	0.40
	Oven-dry volume	0.42
Density, lb/cu ft (kg/cu m)	Green	33 (529)
	Air-dry	28 (448)
	Oven-dry	26 (416)
Density, lb/cu ft (kg /cu m)	Oven-dry weight per green volume	23 (368)

Specific gravity generally decreased with increasing tree height (*10*).

Percent shrinkage, dried to 0% moisture content (*11*): r – 4.3, t – 7.5, v – 11.5.

Percent moisture content, when green	
Green basis	30
Oven-dry basis	42
Percent moisture content oven-dry basis (*11*)	
Heartwood	41
Sapwood	142

One study found that selection for vigor tended to favor trees with reduced density but did not affect tracheid length (*12*). In another study, there were no significant differences in tracheid length between trees grown at different spacings, 2.4 x 2.4 m to 4.57 x 4.57 m. However, density of the wood was significantly greater at the narrow spacing than at the wide spacing (*13*).

Physical Properties of Bark

Specific gravity, green volume (*14*)	Inner bark	0.44
	Outer bark	0.62
Specific gravity, oven-dry weight & volume (*15*)		0.63
Percent moisture content, oven-dry basis (*14*)	Inner bark	112
	Outer bark	55

A general bibliography on Sitka spruce has been compiled by Harris and Ruth (*16*).

Chemical Composition of Wood

Proximate Analyses	F.P.L.	Bloom, Jahn, & Wise (*17*)	Packman & Orsler (*18*)
Lignin, %	29.6	27.4	26.8
C. & B. cellulose, %	60.5	63.3	
Alpha-cellulose, %	44.8		
Pentosans, total, %	9.0	8.1	
Solubility in			
Alcohol-benzene, %	4.5	2.3	0.5
Ether, %	0.8	0.31	
1% NaOH, %	14.9		
Hot water, %	5.0	2.8	
Alcohol-benzene + hot water, %			2.0
Glucose, %			50.0
Mannose, %			17.5
Xylose, %			2.5
Galactose, %			0.7

Rapson, *et al.* (*19*) found 0.45% ash as a percent of dry wood. Additional analyses include Packman and Laidlaw (*20*) and Young *et al.* (*21*).

Extractives. Conidendrin was not found (*22*). Alcohol-benzene extractives removed 2.0% of mature wood, separable into neutral, acidic, and phenolic portions after removal of 0.2% ether-insoluble ligninlike fraction. Phenolic fraction (0.36%) consisted of acetovanillone (0.144%), vanillin (0.144%), and vanillyl alcohol (0.072%) (*23*). For other information on extractives, see Drew and Pylant (*24*).

Carbohydrates. For glucomannans, see Dutton and Walker (*25*).

Other Information. For information on fatty acids and resin acids, see Swan (*26*).

Chemical Composition of Bark

Triterpenes from bark (*27*); extractives from bark (*28*).

Utilization of Wood and Bark

Million of BTU/air-dry cord	15.9
Million kg cal/air-dry cord	4.0

Calorific Value of Wood

4500 kg cal/kg

Use properties of wood. The wood has fine, uniform texture, generally straight grain; it is moderate in weight, stiffness, hardness, resistance to shock, shrinkage, bending, and compressive strength. It is worked easily and is not difficult to kiln dry. It is intermediate in resistance to decay. Thin panels are desirable for piano sounding boards. It is used as ladder stock. It takes a smooth, silvery finish, nails without splitting and holds nails well. It also has excellent gluing properties.

Pulping

Mechanical. The wood is readily reduced; the pulp is slightly creamy in color and of good strength; power requirement similar to white spruce (*29-31*). Pulp property differences due to specific gravity are very small compared to kraft pulp (*32*).

Kraft. The wood is readily reduced, yield is normal, and the pulp is moderately strong and bleaches easily; it is used for high-grade wrapping papers and fiberboard (*31*). Density of wood in crown markedly higher, in many cases, than bolewood, and pulps from this topwood were of poorer quality (*33*). See Horn and Auchter (*34*) for pulp characteristics.

Sulfite. The wood is readily reduced, yield is normal, and the pulp is moderately strong and of excellent color and is easily bleached; pitch prevents use of higher proportion in cook; it is used for newsprint, wrapping, book, high-grade printing and bond papers (*31*). Texture is not quite as fine as that of white spruce.

Two-stage bisulfite. The wood can be pulped by the 2-stage Stora-Brite process with spruce giving higher yield than larch (*35*). According to Young and Packman (*36*), there was complete uniformity of delignification in 2-stage bisulfite pulping at kappa no. as high as 78. Screened yields as high as 65% of original wood were obtained without mechanical defibration.

One-stage Na bisulfite. A decrease in degree of delignification in single-stage pulps necessitated extension of the pulping reaction, compared to the 2-stage process cited above, to yields substantially lower than those of the 2-stage process (*36*).

Refiner groundwood. This has higher brightness, breaking length, burst and tear strength than Scotch pine, Douglas-fir, grand fir, western hemlock and Japanese larch (*37*).

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 445, 1973.

2. USDA, Forest Service. Agriculture Handbook No. 271, 1965.

3. Dinwoodie, J. V. Forestry 35(1):22-6(1962).

4. Chalk, L. Forestry 4:7-14(1930).

6. Britt, K. W. Tappi 48(1):7-11(1965).

5. Sastry, C. B. R.; Wellwood, R. W. Tappi 55(6):901-3(1972).

7. Elliott, G. K. J. Inst. Wood Sci. 5:38-47(1960).

8. Smith, J. H. G.; Kozak, A. Mimeo of "Thickness and percentage of bark of the commercial trees of British Columbia," University of British Columbia, Faculty of Forestry, 1967.

9. Chang, Y.-P. USDA, Tech. Bull. No. 1095, 1954.

10. Farr, W. A. Wood Sci. 6(1):9-13(1973).

11. USDA, Forest Service. Forest Prod. Laboratory. Agriculture Handbook No. 72, 1974.

12. Brazier, J. D. Forestry 40(2):117-28(1967).

13. Ward, D. D.; Gardiner, J. J. Irish Forestry 33(1):39-56(1976).

14. Smith, J. H. G.; Kozak, A. Forest Prod. J. 21(2):38-40(1971).

15. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv., Res. Note FPL-091, 1969.

16. Harris, A. S.; Ruth, R. H. USDA, Forest Serv., Res. Paper No. PNW-105, 1970.

17. Bloom, P.; Jahn, E. C.; Wise, L. E. Tech. Assoc. Papers 25:578(1942); Paper Trade J. 115(10):33(1942).

18. Packman, D. F.; Orsler, R. J. Holzforsch. 18(6):179-83(1964).

19. Rapson, W. H.; Wayman, M.; Anderson, C. B. Pulp Paper Mag. Can. 66(5):T255-71(1965).

20. Packman, D. F.; Laidlaw, R. A. Holzforsch. 21(2):38-45(1967).

21. Young, W. D.; Laidlaw, R. A.; Packman, D. F. Holzforsch. 24(3):86-98(1970).

22. Erdtman, H. Svensk Papperstidn. 47:155(1944).

23. Kohlbrenner, P. J.; Schuerch, C. J. Agr. Chem. 24(2):166-72(1959).

24. Drew, J.; Pylant, G. D., Jr. Tappi 49(10):430-8(1966).

25. Dutton, G. G. S.; Walker, R. H. Cellulose Chem. Technol. 6(3):295-305(1972).

26. Swan, E. P. Can. Dept. Forestry, Inform. Rept. VP-X-115, 24 p. (Aug., 1973).

27. Kutney, J. P.; Rogers, I. W.; Rowe, J. W. Tetrahedron 25:3731-51(1969).

28. Rogers, I. H. Ph.D. Thesis, Univ. of British Columbia, 1967. (Microfilm) Diss. Abstr. 28(8):3228-9B(Feb., 1968).

29. Hatch, R. S.; Holzer, W. F. TAPPI Monograph No. 4:153(1947).

30. Thickens, J. H.; McNaughton, G. C. USDA Bull. No. 343, 1916.

31. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485, 1927, 101 p.

32. Packman, D. F.; Laidlaw, R. A. Holzforsch. 20(5):155-9(1966).

33. Packman, D. F. Holzforsch. 24(3):99-102(1970).

34. Horn, R. A.; Auchter, R. J. Applied Polymer Symposium No. 28, 1976, p. 529-39.

35. Dewhirst, L.; Rusten, D. Paper Technol. 8(3):258-63(1967).

36. Young, W. D.; Packman, D. F. Appita 21(5):144-53(1968).

37. Packman, D. F. Paper Technol. 8(4):339-40(1967).

BLUE SPRUCE

Scientific Name *Picea pungens* Engelm.

Synonyms Colorado blue spruce, Colorado spruce, silver spruce

Family Name Pinaceae

Range Rocky Mountain region in high mountains from western Wyoming and southeastern Idaho south to Utah, northern and eastern Arizona, New Mexico, and central Colorado, at elevations of 6000-9000 ft (1830-2740 m) in the north and 8000-11,000 ft (2440-3350 m) in the south.

Silvics The symmetrical bole is supported by a wide-spreading but moderately deep root system. The crown is typically conical, and that of open-grown trees usually extends to the ground. This species is largely restricted to the middle and upper slopes of the central Rocky Mountains, mostly below the Engelmann spruce belt. It is usually found singly or in small groves. At lower altitudes it is common in the ponderosa pine forests, along the banks of streams. At higher elevations it mingles with subalpine fir and Engelmann spruce. An abundance of seed is produced every two to three years. Growth is slow throughout most of its range. The species is rated as intermediate in tolerance.

Tree Dimensions 80-100 ft (24-30 m) tall and 12-24 inches (30-61 cm) in diameter.

Pathology

Blue spruce is susceptible to a number of heart, butt and root rots. These include *Fomes officinalis, Phellinus pini, Fomes pinicola, Polyporus tomentosus, Phaeolus schweinitzii* and *Armillariella mellea*.

The western spruce budworm (*Choristoneura occidentalis*), as well as *C. fumiferana*, are highly destructive to blue spruce, feeding on buds and foliage of the current year. Sustained attacks can cause complete defoliation in 4-5 years. Other less important insect pests include the Cooley spruce gall aphid (*Adelges cooleyi*) and the yellowheaded spruce sawfly (*Pikonema alaskensis*).

Gross Features of the Wood See the description for red spruce.

Microscopic Structure of the Wood See the description for red spruce.

Tracheids. Average 2.8 mm in length. Weight factor (unbleached kraft) 0.90.

Gross Features of the Bark Thin; divided into ashy-gray or brownish-gray, loosely attached scales, later thick and furrowed.

Physical Properties of Wood

Basic density, lb	23

Pulping

Kraft. The wood is readily reduced, and it is strong and of fine texture.

Sulfite. The wood is readily reduced, and it is strong, of fine texture and excellent color; it is easily bleached to an excellent white.

Mechanical. The wood is readily reduced and is of excellent color and standard strength; power required is comparable to that for white spruce.

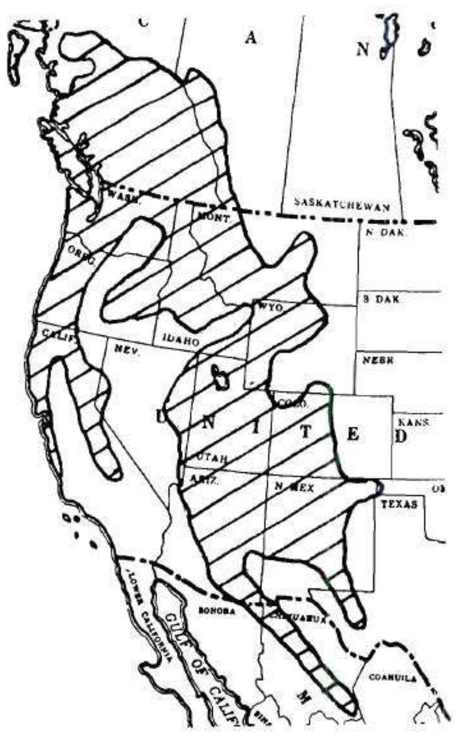
DOUGLAS-FIR

Scientific Name *Pseudotsuga menziesii* (Mirb.) Franco

Synonyms Red fir, Oregon pine, Douglas-spruce, yellow fir

Family Name Pinaceae

Range Western United States and British Columbia. Along the coast it occurs from sea level to 5000 ft (1520 m); but inland it is usually at an elevation of 4000-6000 ft (1220-1830 m) above sea level; up to 10,000 ft (3050 m) in the southern Rockies. Coastal Douglas-fir covers about 17 million acres (6.9 million ha) while Rocky Mountain Douglas-fir, together with ponderosa pine, covers 20 million acres (8.1 million ha) in the interior northwest.



Silvics There are two forms of this species, the coastal form (var. *menziesii*) and the Rocky Mountain or inland form (var. *glauca*). The differences are in the structure of the cones, foliage color (yellow-green for the coastal form and blue-green for the Rocky Mountain form), growth rate and environmental requirements.

Coastal form. Douglas-fir is a very large tree, next to the giant sequoia and redwood in size. Old trees have an exceptionally clear, long cylindrical bole, either a rounded or an irregularly flat-topped crown, and a strong, well-developed, wide-spreading, lateral root system. The best growth is made on deep, rich, well-drained porous loams in regions where there is an abundance of both soil and atmospheric moisture. During its early growth, Douglas-fir forms extensive, pure, even-aged stands, but these are later invaded by other, more tolerant species. The species is intermediate in shade tolerance when ranked with all other commercial conifers in the west.

Rocky Mountain form. This form occurs in pure and mixed stands. In mixtures, its associates are ponderosa, lodgepole and western white pines and western larch. This form is the climax species over most of the type.

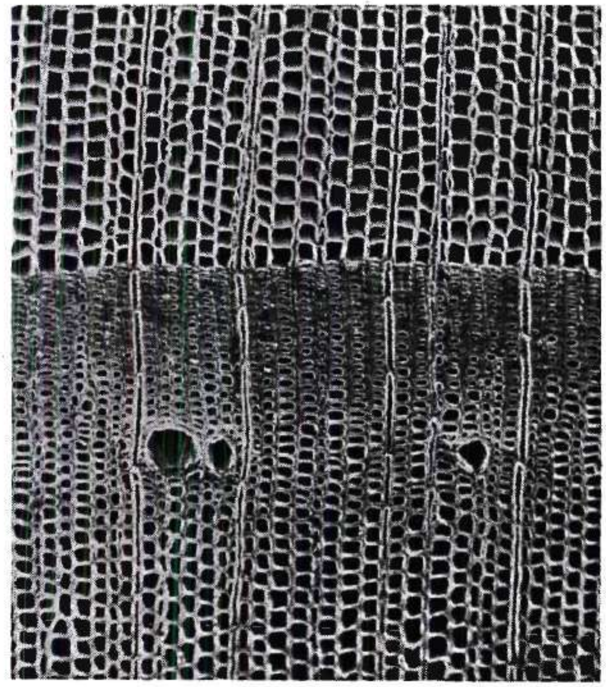
Tree Dimensions Coastal form – 180-250 ft (55-76 m) tall and 4-6 ft (120-180 cm) in diameter. Rocky Mountain form – 100-120 ft (30-37 m) tall and 15-30 inches (38-76 cm) in diameter.

Pathology Resistance to decay: moderately durable.

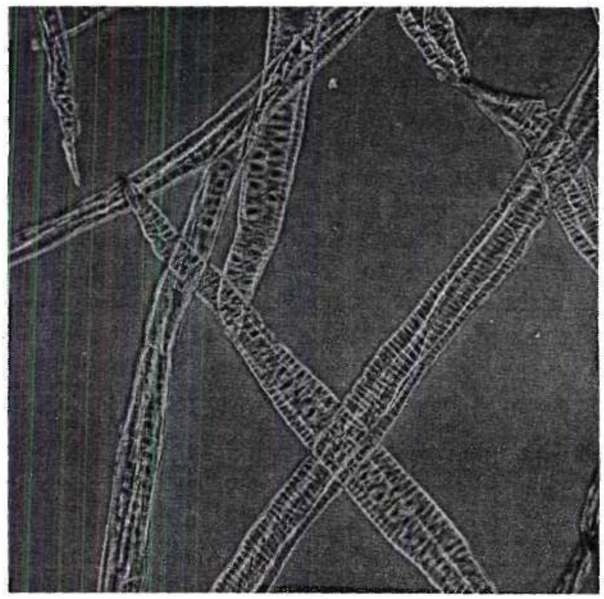
Heartwood rot by the ring scale conk rot fungus (*Phellinus pini*) is severe, particularly in the southern part of the range. The most serious fungus enemy of Douglas-fir is *Poria weirii*, a killing root disease. Both *P. weirii* and *Phaeolus schweinitzii*, heartwood decay fungi, kill old trees by contributing to uprooting or breakage near the ground (*1*). Another heartwood decay in young Douglas-fir is caused by *Fomes subroseus*, which gains entrance through broken tops. Dwarf mistletoe (*Arceuthobium douglasii*) is one of the most damaging diseases of the Rocky Mountain variety of Douglas-fir.

The Douglas-fir tussock moth (*Orgyia pseudotsugata*) is a defoliator of major importance on Rocky Mountain Douglas-fir. The Douglas-fir beetle (*Dendroctonus pseudotsugae*) is the most important bark beetle enemy of Douglas-fir, attacking trees from the large pole stage to maturity. The flat-headed fir borer (*Melanophila drummondi*) causes similar but less extensive damage, generally attacking injured, dying or recently felled trees. The striped ambrosia beetle (*Trypodendron lineatum*), the most damaging ambrosia beetle in the west, creates galleries in wood, consisting of small holes surrounded by brown or black stain (*2*). The black spruce borer (*Asemum striatum*) is the most abundant borer in Douglas-fir killed by fire.

Gross Features of the Wood The sapwood is whitish to pale yellowish or reddish, and the heartwood ranges from yellowish or pale reddish-yellow to orange-red or deep red. The wood varies considerably in hardness and weight and has a characteristic resinous odor when fresh, which is different from that of pine, but no characteristic taste. The springwood is usually several times wider than the summerwood; the transition is abrupt. The summerwood is pronounced, very narrow in slow-grown stock to very wide and dense in wide rings. The growth ring is conspicuous. The Rocky Mountain form is narrow ringed, fine grained, uniform textured, moderately soft, and easily worked, whereas the coastal form is wide ringed, coarser grained, and more uneven textured. In the x-section the rays are very fine, not visible with the naked eye, and form a fine, close, inconspicuous fleck on the radial surface. Both longitudinal and horizontal resin canals are present. The longitudinal canals are small, barely visible or indistinct with the naked eye, and plainly visible with a hand lens as dark spots or openings which are confined largely to the outer half of the growth ring. They may be sparse and scattered or numerous and exhibit more or less of a tendency toward tangential rows of 2-30+. The transverse canals are smaller and appear with a hand lens as somewhat broader rays spaced at irregular intervals on the transverse surface. Longitudinal parenchyma are not visible. Additional information in this area includes Krahmer (*3*), Lassen (*4*), Lassen and Okkonen (*5*), and Smith, *et al.* (*6,7*).



Cross section of Douglas-fir showing portions of two growth rings. Transition between earlywood and latewood is abrupt. Resin ducts are visible. Magnification 90X.



Douglas-fir springwood fibers showing spiral thickening and pits. Magnification 110X.

Microscopic Structure of the Wood

Tracheids. Average 3.9 mm (1.7-7.0 mm) in length and 35-45 μm in diameter. Cell wall thickness averages 3.41 μm. Weight factor (unbleached kraft) 1.40 coastal and 0.90 Rocky Mountain and coarseness range of 26-31 mg/100 m. Spiral thickening is present on nearly all tracheids; bordered pits in one row or occasionally paired on the radial walls; tangential pitting present in the last few rows of summerwood tracheids; pits leading to ray parenchyma are small, quite uniform in size, with distinct border, 1-6 (generally 4) per ray crossing; ray tracheid pits present; volume occupied, approximately 92%.

Resin Canals. Longitudinal, 60-90 μm in diameter; horizontal, usually less than 25 μm in diameter; thick-walled, epithelial cells; volume occupied, <1%.

Rays. Two types, uniseriate or rarely in part biseriate, and fusiform. The uniseriate rays are numerous and 1-12+ cells high. Biseriate rays, if present, are very sparse and scattered. The fusiform rays are scattered, with one or very rarely two horizontal resin canals, 3- to 5-seriate in the central portion, tapering to uniseriate margins; up to 16+ cells high. Ray tracheids are present in both types, marginal and very rarely interspersed, nondentate inner walls, occasionally with spiral thickening; marginal usually in one row. Volume occupied, approximately 7%.

Longitudinal Parenchyma. Terminal and very sparse, or absent.

Gross Features of the Bark On young stems the bark is grayish and rather smooth, except for resin blisters. On mature trees, the bark has reddish-brown ridges separated by deep, irregular fissures. Quite variable, it is usually 1-2 inches (2.5-5.0 cm) thick on thin-barked trees and 5-6 inches (13-15 cm) and up to 12-24 inches (30-60 cm) on very old, thick-barked trees. The periderm, thin in young stems, is well developed in old or thick-barked trees and, in cross section, is variable from fine lines to very broad bands of about 1/2-inch (1.2 cm) wide, composed of 15 or more rows of periderm cells. The light, creamy yellow periderm bands are in great contrast to the deep, brilliant-brown, fibrous, isolated secondary phloem tissue of the rhytidome. Cork, which originates from the cork cambium, is in large quantities in Douglas-fir bark (30-50% of the bark dry weight) and greatly affects bark properties. Douglas-fir bark ranges between 8 and 15% of the log volume on a cubic foot basis. Additional information in this area includes Ross and Krahmer (*8*).

Microscopic Structure of the Bark

Phloem Fibers. Average 1-1.5 mm in length and 50-100 μm in diameter. Sclereidlike. They differentiate from cells in the parenchyma strands rather early, some during the third year, and gradually increase in number for years. Comprising most of the bark volume by weight, with the exception of the "cork," these fibers appear singly or in groups of 2-6 without definite pattern. Cell walls are very thick with distinct lamellate layers. Although branched and forked forms are not uncommon, most of these sclereids are elongated with pointed ends.

Sieve Cells. Average 3-4 mm in length. Near the cambial zone, thin-walled sieve cells are regularly arranged, usually three in a radial row, interspersed with parenchyma cells. Sieve areas appear on the radial walls, usually in single, vertical rows. As distance increases from the cambium, the sieve cells collapse and become obliterated.

Parenchyma. Three types prevail in the secondary phloem. Thin-walled parenchyma cells are somewhat rectangular in cross section and up to 50 μm in diameter close to the cambium, becoming more oval and expanding in the outer bark. Parenchyma strands are the most abundant form and longitudinally, some have the same length as the sieve cells. Dispersed parenchyma strands are very common in young trees; the cells that do not sclerify increase in diameter each year, crushing the sieve cells. Fusiform parenchyma are much more abundant in the secondary phloem of young trees, with only a small percentage in older trees. Fusiform parenchyma differs from the strand parenchyma in that most of the cells accumulate a clear, resinous material and develop cubical crystals, after which the cells collapse radially and become crushed. Marginal erect cells, or albuminous cells that do not collect tannins, resins, or crystals, are conspicuous along the margins of the uniseriate rays close to the cambial zone and may occur in strands.

Rays. Rays are of two types, usually uniseriate and fusiform. Uniseriate rays, in young trees only a few cells high, are usually 8-15 cells high or 200-350 μm in height in tangential section. Fusiform rays, absent in young stems, are abundant in older trees and contain the horizontal resin canals.

Physical Properties of Wood

		Coastal Form	Intermediate Form	Rocky Mountain Form
Specific gravity	Green volume	0.45	0.41	0.40
	Air-dry volume	0.48	0.44	0.43
	Oven-dry volume	0.51	0.46	0.45
Density, lb/cu ft (kg/cu m)	Green	38 (609)	35 (561)	34 (545)
	Air-dry	34 (545)	31 (497)	30 (481)
	Oven-dry	32 (513)	29 (464)	28 (448)
Density lb/cu ft (kg/cu m)	Oven-dry weight per green volume	28 (448)	26 (416)	25 (400)

Overall decrease in specific gravity with increase in height of tree (*9*).

Specific gravity increased with age to about 16-18 years, then leveled off (*10*).

Percent shrinkage (*11*), dried to 20% moisture content: r – 1.7, t – 2.6, v – 3.9; dried to 6% moisture content: r – 4.0, t – 6.2, v – 9.4; dried to 0% moisture content: r – 5.0, t – 7.8, v – 11.8.

Percent moisture content, when green

Green basis	26
Oven-dry basis	36

Percent moisture content oven-dry basis (*11*)

Heartwood	37
Sapwood	115

Additional information in this area includes McKimmy (*12*) and Salamon and Kozak (*13*).

Physical Properties of Bark

Specific gravity green volume	Inner bark	0.42
	Outer bark	0.40
	Total bark	0.41
Density (100% moisture content)	Green weight/ green volume	0.82
Percent moisture content oven-dry basis (*14*)	Inner bark	133
	Outer bark	80

Chemical Composition of Wood

Proximate Analyses

	Martin (*15*)	Bray *et al.* (*16*)*	Wise and Ratliff (*17*)
Lignin, %	27.2	25.3-29.6	28.4
Holocellulose, %	67.0	–	–
C. & B. cellulose, %	–	54.0-66.0	–
Alpha-cellulose, %	50.4	38.4-46.5	57.2; 48.3
Hemicellulose, %	–	–	14.1
Ash, %	0.2	–	0.29
Total, %			
Total, %	6.8	7.5-10.6	–
In cellulose, %	7.9	–	–
Mannan, %	–	–	5.4
Acetyl, %	–	–	0.61
Xylan, %	–	–	6.20
Uronic anhydride, %	–	–	2.80
CH_2 (from MeO not in lignin), %	–	–	92.05
Solubility in			
Alcohol-benzene, %	4.4	1.5-5.7	–
Ether, %	1.2	0.3-2.6	–
1% NaOH, %	15.1	10.9-18.3	–
Hot water, %	5.6	2.0-6.6	–

*Range of 18 samples.

The Klason lignin content is 0.316 g/g (*18*). The Institute of Paper Chemistry, Project 3212, Report 2 finds that 4.4% of the wood is soluble in alcohol-benzene.

Carbohydrates

	Smith & Zavarin (*19*) Sapwood	Heartwood
Glucose, %	0.1	0.02
Fructose, %	0.1	–
Sucrose, %	0.1	–
Raffinose, %	0.02	–
Stachyose, %	tr.	–
Arabinose, %	–	0.04
Xylose, %	–	?
Rhamnose, %	–	tr.

Extractives

	Corder (*20*)
Volatile matter, %	86.2
Carbon, %	13.7
Ash, %	0.1

3,3′,4′,5,7-Pentahydroxyflavanone was isolated from the heartwood (*21,22*), as was taxifolin (Erdtman, *23*).

The yield of tannin from sawdust was 1.1% (*24*).

Oleic, linoleic, lignoceric, and abietic acid, phytosterol, and tannin were found in the ether extract of heartwood. A pentahydroxyflavanone and a catechol tannin and phlobaphene were isolated from the acetone extract. Approximately 70% of the cold-water extract was a galactan (*25*).

For information on petroleum ether- and acetone-soluble fractions, see Rogers *et al.* (*26*). For general information on extractives, see Drew and Pylant (*26*) and Laver *et al.* (*28*).

Additional information on the chemical composition of wood includes Squire, *et al.* (*29*), Zavarin and Snajberk (*30*), Drew and Pylant (*27*), Rogers, *et al.* (*26*), Chidester and McGovern (*31,32*), Martin (*33*), Bailey (*34*) and Kurth (*35*).

Chemical Composition of Bark

	Weyerhaeuser (*36*)	The Institute of Paper Chemistry Project 3212 Report 2
Carbon, %	53.0	
Oxygen, %	39.3	
Calcium, %	–	0.3
Silica, %	–	0.06
Ash, %	1.5	1.2

Extractives. Alcohol-benzene extractives are 16.4%. For information on hexane-soluble components, see Fang (*37*); on extractives, Loveland and Laver (*38*).

Other Information. For information on elements in bark, see Harder and Einspahr (*39*). For information on the chemical constituents of bark, see Laver, *et al.* (*28*). For carbohydrates of the inner bark, see Laver, *et al.* (*40*). For information on bark waxes and corks, see Kurth (*41*).

Pulping

Alcohol and SO_2. This can be used at high pressure as can acetic acid and SO_2.

Kraft. The wood is readily reduced and yield is normal. Due to large fibers it is necessary to use larger openings in the screen plates, usually by about 25%. Pulp is quite free and, because of its good drainage on the wire, it requires more water in the headbox. Large fibers make the sheet more porous and, therefore, more easily dried, but they also make the paper bulky and low in finish. Outstanding tearing resistance but a low bursting strength seem to be caused by summerwood fibers. Dark colored pulp can be bleached to high whites but not as readily as pulps from hemlock.

For kraft pulping information, see Hatton (*42*) and Wang (*43*). Kraft pulp can be used for nitrating-grade pulps and waterleaf sheets. Pretreatment with H_2S and NaOH prior to kraft pulping increases yield and quality of pulps. For information on the hydrogen sulfide kraft process, see Vinje and Worster (*44*). Polysulfide added to kraft liquor increases the yield (*45*). Forest-residual chips can be used to supplement conventional chips in a kraft mill in amounts greater than 10% (*46*).

Sawdust can be kraft pulped (*47*); tear strength is low because of short fiber length (*48*).

Mechanical. Wood from young trees up to 15 inches is suitable; strength is good; color is creamy; although foam from pitch and extractives limit amounts usable, up to 30% of total can be used. Old growth is not suitable for the generally acceptable grades of groundwood pulp except when pretreated with steam or hot dilute alkali, after which it can be ground for pulp suitable for shipping container boards.

Nitric acid. This can be used.

NSSC. The pulp is used for corrugating medium. The pulp is strong (*49*).

Oxygen-alkali. Although the yield is low, pulps are as strong as kraft pulps.

Soda pulping. Pretreatment with H_2S improves yield.

Sulfite. Magnesium bisulfite pulping gives a pulp of good strength; CEHD bleaching gives brightness of about 70%. Alkaline sulfite pulping with 0.2-2% sodium borohydride gives pulp stronger than kraft pulp. Sulfite pulping followed by oxygen-alkali delignification gives pulps of higher yield than with the kraft process; duplex linerboards from this pulp are equivalent to kraft or better. The wood is resistant to calcium bisulfite pulping. Heartwood can be pulped by sodium or magnesium two-stage processes using bisulfite-alkaline sulfite or bisulfite-neutral sulfite cooking liquors. Pretreatment with NaOH and HCHO prior to acid sulfite pulping makes pulp suitable for glassine paper.

Additional information on pulping includes Cox and Worster (*50*), Fahey and Martin (*51*), Horn and Auchter (*52*), Legg and Hart (*53*), Wells, *et al.* (*54*), and Worster and Pudek (*55*).

Bleaching

Flavonoid extractives are responsible for poor brightness and bleachability (*56*).

Heartwood older than 40 years is resistant to peroxide bleaching. Pulp from trees up to 40 years of age can be bleached to 72-74 brightness with 3-4% peroxide. For information on chlorination of kraft pulps, see Ackert (*57*).

Utilization of Wood and Bark

Use properties of wood. Wood varies widely in quality, both in the Pacific coast type and to a lesser extent, in the Rocky Mountain type. Average material from the coast is strong, moderately hard, moderately heavy and stiff. The mountain type averages considerably below that from the coast in weight and in strength properties. It splits easily, is rather difficult to work, is difficult to impregnate, is low in paint-holding ability, can be glued satisfactorily with moderate care, is easily seasoned and has high shrinkage.

Calorific Value of Wood

22.2-24.3 x 10^6 BTU/air-dry cord
(5.6 to 6.1 kg cal)

Heartwood, 7500 BTU/lb
(4167 kg cal/kg)

Calorific Value of Bark

9962 BTU/o.d. lb
(5535 kg cal/kg)

252,595 BTU/ft^3
(1800 kg cal/m^3)

Chemical uses of bark. The bark is used for pyrolyzates, extractives, and tannin. Bark is also used to make wax, to make a phenol substitute used to strengthen plastics, and as a powdered extender for thermoset resins.

Bark phenolic acid can be used to make adhesives and coatings. The bark can also be used as the polyol in making a polyurethane foam that is highly thermally stable and fire resistant (*60*).

A sodium carbonate extract of the bark is used to make a binder for 3-layer wood particle boards (*61*).

Other uses of wood. The wood is used for plywood, lumber, veneer, poles, piling, cooperage, fuelwood, fence posts, railroad ties, and mine timbers. Lumber is principally for sash, door, and general millwork, boxes and crates, car construction and repair, flooring, furniture, ships and boards, fixtures, wood pipe, and tanks. Glued, laminated timber is used for beams and arches. Forest residues can be used to make random-flake flakeboard (*58*). Green and dry wood waste and log ends are used in hardboard (*59*).

Other uses of bark. The bark is used for fuel, charcoal, tiles, building board, mulch, soil conditioner, and compost. Bark fibers can be used in a thermoplastic molding composition (*62*). Cork is used in tile and veneer patching.

Literature Cited

1. USDA, Forest Service, Agriculture Handbook No. 271, 1965, 762 p.
2. Furniss, R. L.; Carolin, V. M. USDA, Forest Serv. Misc. Publ. No. 1339, 1977, 654 p.
3. Krahmer, R. L. Forest Prod. J. 11(9):439-41(1961).
4. Lassen, L. E. Dissert. Abstr. 28B (12, Part 1), (4842), 1968.
5. Lassen, L. E.; Okkonen, E. A. U.S. Forest Serv. Res. Pap. U.S. Forest Prod. Lab. No. FPL-124, 1969, 16 p.
6. Smith, J. H. G.; Walters, J.; Wellwood, R. W. Forest Sci. 12(1):97-103(1966).
7. Smith, J. H. G.; Heger, L.; Hejjas, J. Can. J. Botany 44:453-66(1966).
8. Ross, W. D.; Krahmer, R. L. Wood Fiber 3(1):35-46(1971).

9. Okkonen, E. A.; Wahlgren, H. E.; Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).

10. Erickson, H. D.; Harrison, A. T. Wood Sci. and Technol. 8:207-26(1974).

11. U.S. Forest Products Laboratory, Agriculture Handbook No. 72, 1974.

12. McKimmy, M. D. Tappi 49(12):542-9(1966).

13. Salamon, M.; Kozak, A. Forest Prod. J. 18(3):90–4(1968).

14. Smith, J. H. G.; Kozak, A. Forest Prod. J. 21(2):38-40(1971).

15. Martin, J. S. Tappi 32:534(1949).

16. Bray, M. W.; Schwartz, S. L.; Martin, J. S. Tech. Assoc. Papers 23:232(1940).

17. Wise, L. E.; Ratliff, E. K. Anal. Chem. 19:459(1947).

18. Musha, Y.; Goring, D. A. I. Wood Sci. 7(2):133-4(Oct., 1974).

19. Smith, L. V.; Zavarin, E. Tappi 43(3):218-21 (March, 1960).

20. Corder, S. E. 1973. Oregon State Univ., Forest Research Laboratory, Corvallis. Research Bulletin 14.

21. Pew, J. C. J. Am. Chem. Soc. 70:2021(1948).

22. Pew, J. C. Tappi 32:39(1949).

23. Erdtman, H. Progress in Organic Chemistry 1:22-63(1952).

24. Benson, H. K.; Thompson, T. G. J. Ind. Eng. Chem. 7:915(1915).

25. Graham, H. M.; Kurth, E. F. Ind. Eng. Chem. 41:409(1949).

26. Rogers, I. H.; Harris, A. G.; Rozon, L. R. Can. Dept. Forestry Inform. Rept. VP-X-57: 29 p. (Dec., 1969).

27. Drew, J.; Pylant, G. D., Jr. Tappi 49(10):430-8 (Oct., 1966).

28. Laver, M. L.; Loveland, P. M.; Chen, C. H.; Fang, H. H.-L.; Zerrudo, J. V.; Liu, Y.-C. L. Wood Sci. 10(2):85-92(Oct., 1977).

29. Squire, G. B.; Swan, E. P.; Wilson, J. W. Pulp Paper Mag. Can. 68(9):T431-7(Sept., 1967).

30. Zavarin, E.; Snajberk, K. Phytochem. 4(1):141-8(Feb., 1965).

31. Chidester, G. H.; McGovern, J. N. Tech. Assoc. Papers 23:322(1940); Paper Trade J. 110(10):39(March 7, 1940).

32. Chidester, G. H.; McGovern, J. N. Tech. Assoc. Papers 24:226(1941); Paper Trade J. 113(9):34 (Aug. 28, 1941).

33. Martin, J. S. Tech. Assoc. Papers 29:268(1946); Paper Trade J. 122(22):37(1946).

34. Bailey, A. J. Mikrochemie 19:98(1936).

35. Kurth, E. F. Tech. Assoc. Papers 31:614(1948); Paper Trade J. 126(6):56(Feb. 5, 1948).

36. Weyerhaeuser Co. Waste Wood Utilization for Energy. An in-house document of the Fuels and Combustion Section of Weyerhaeuser Co., Tacoma, WA, Oct., 1973.

37. Fang, H. H.-L. Oregon State Univ., Ph.D. Thesis, 1974: 121 p. [Univ. Microfilms, Ann Arbor, Mich.].

38. Loveland, P. M.; Laver, M. L. Phytochem. 11(1):430-2(Jan., 1972) and 11(10):3080-1(Oct., 1972).

39. Harder, M. L.; Einspahr, D. W. To be submitted to Tappi.

40. Laver, M. L.; Chen, C.-H.; Zerrudo, J. V.; Lai, Y.-C. L. Phytochem. 13(9):1891-6(Sept., 1974).

41. Kurth, E. F. Tappi 50(6):235-8(June, 1967).

42. Hatton, J. V. Tappi 59(8):48-50(Aug., 1976).

43. Wang, P. H. Oregon State Univ. Ph.D. Thesis, 1974: 176 p.

44. Vinje, M. G.; Worster, H. E. Tappi 53(6):1082-6(June, 1970).

45. Sanyer, N.; Laundrie, J. F. Tappi 47(10):640-52(Oct., 1964).

46. Hatton, J. V. Brit. Columbia Lumberman. June, 1975: 4 p.

47. Bublitz, W. J.; Hull, J. L. TAPPI Forest Biol./ Wood Chem. Conf. (Madison) Papers: 177-81(June 20-22, 1977).

48. Bublitz, W. J.; Yang, T. Y. Tappi 58(3):95-9 (March, 1975).

49. McGovern, J. N.; Keller, E. L.; Martin, J. S.; Kingsbury, R. M. USDA, Forest Prod. Lab. Rept. 1912(Dec., 1951).

50. Cox, L. A.; Worster, H. E. Pulp Paper Mag. Can. 73(9):106-9(T250-3)(Sept., 1972).

51. Fahey, D. J.; Martin, J. S. Madison, WI, U.S. Forest Prod. Lab. [Rept. 2200] April, 1961. 37 p.

52. Horn, R. A.; Auchter, R. J. Paper Trade J. 156(46):55-9(Nov. 6, 1972).

53. Legg, G. W.; Hart, J. S. Pulp Paper Mag. Can. 61(5):T299-304(May, 1960).

54. Wells, F. L.; Herdle, L. E.; Walker, A., Jr. Tappi 52(11):2136-40(Nov., 1969).

55. Worster, H. E.; Pudek, M. F. Pulp Paper Mag. Can. 75(1):126-30(T2-6)(Jan., 1974).

56. Betz, R. G.; Styan, G. E. Pulp Paper Mag. Can. 75(C):111-4(T121-4) (March, 1974).

57. Ackert, J. E. Univ. Idaho Ph.D. Thesis, 1973: 267 p.

58. Gardner, R. B.; Schaffer, E. L.; Erickson, J. R. USDA, Forest Serv. Res. Paper No. INT-200: 36 p. (March, 1978).

59. Lowood, J. D. Pulp Paper Mag. Can. 75(1):149-51(T25-7)(Jan., 1974).

60. Hartman, S. Champion Internat. Corp. U.S. pat. 4,032,483.

61. Anderson, A. B.; Wong, A.; Wu, K.-T. Forest Prod. J. 25(3):45-8(March, 1975).

62. Hendrickson, H. E.; McCain, C. N.; Weyerhaeuser Co. U.S. pat. 3,577,368 and 3,577,369.

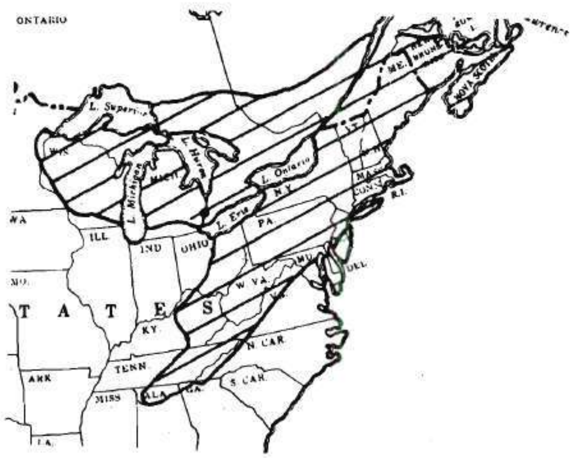
EASTERN HEMLOCK

Scientific Name *Tsuga canadensis* (L.) Carr.

Synonyms Canada hemlock, hemlock spruce, hemlock

Family Name Pinaceae

Range Southern Canada, Northeast, Lake States, and Appalachians.



Silvics The tree has a tapered bole, a ragged crown, and a superficial, wide-spreading root system. Self-pruning is very poor. Hemlock is found on many types of soil but it reaches its best development in cool, moist situations. In the north, the common associates include white pine, red spruce, white spruce, yellow birch, sugar maple, beech and basswood; farther south, white ash, yellow-poplar, basswood, and various white and red oaks are common. The species is rated as very tolerant.

Tree Dimensions Medium-sized tree; 60-70 ft (18-21 m) tall and 2-3 ft (61-91 cm) in diameter.

Pathology Resistance to decay: low+

Eastern hemlock is relatively free of disease problems. However, old trees commonly contain butt rot. These rots include *Polyporus sulphureus, Poria subacida* and *Phellinus pini*. Although they seldom kill trees, the root rot fungi, *Armillariella mellea, Heterobasidion annosum* and *Phaeolus schweinitzii*, attack eastern hemlock.

Defoliators of eastern hemlock include two species of hemlock loopers, *Lambdina fiscellaria* and *L. athasaria athasaria*. The young larvae feed on the current year's foliage and older larvae, on older needles. The only other insect of economic importance is the hemlock borer (*Melanophila fulvoguttata*). Attacked by the hemlock borer are slow-growing, weakened or recently felled trees.

The species is subject to windthrow due to its shallow root system.

Gross Features of the Wood The sapwood is buff to light brown and not distinct from the heartwood. The latewood frequently has a roseate or reddish-brown tinge. The wood is soft to moderately hard, moderately light, uneven grained, dry and brittle, subject to wind-shake, medium textured; odorless or sour when fresh, without characteristic taste. Flat grain boards exhibit a distinct but not conspicuous growth ring. The earlywood occupies at least two thirds of the growth ring, and there is usually an abrupt transition to the latewood, which is decidedly darker and denser than the earlywood and varies in thickness. Normally, resin canals are absent, and traumatic canals are very rare. In the x-section the rays are very fine, not distinct with the unaided eye, and form a fine, close, inconspicuous fleck on the radial surface. Longitudinal parenchyma cells are not visible. Young, *et al.* (*1*) discuss the weight of wood substance for components of hemlock.

Microscopic Structure of the Wood

Tracheids. Average 3.0 mm in length and 28-40 μm in diameter. Weight factor (unbleached kraft) of 0.90. Bordered pits in 1-2 (mostly 1) rows on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma small, quite uniform in size (piceoid to cupressoid), with distinct border, 1-5 (generally 3-4) per cross field; ray tracheid pits present. Volume occupied, approximately 94%. Shepard and Bailey (*2*) found the average fiber length increased outward from the center of the tree but fluctuated widely in the outer rings. Fegel (*3*) found that root tracheids averaged 2.1 mm. A publication on fiber coarseness in eastern hemlock is Britt (*4*).

Resin Canals. Absent.

Rays. Uniseriate, 1-12+ cells in height; ray tracheids present, usually restricted to one row on the upper and lower margins of the ray. Volume occupied, approximately 6%.

Longitudinal Parenchyma. Terminal and very sparse, or absent. Timell has made observations on rays in compression wood (*5*).

Gross Features of the Bark (*6*) On young trees flaky or scaly, soon with wide, flat ridges, and on old trees heavily and deeply furrowed. Bark on mature trees may be up to 3 inches (7.6 cm) thick at the base. Outer bark is dull brown with pinkish-colored layers of periderm on cross section. Inner bark is light cream yellow when it is fresh, turning reddish-brown after exposure. The secondary phloem is usually about 0.15-0.2 inch (0.38-0.5 cm) wide and shows sporadic spots of sclereid groups. According to Young (*7*), the bark of various components as a percentage of the complete tree bark amounted to: branches and unmerchantable top – 15%, merchantable bole – 59%, and stump and roots – 26%. A publication on bark volume is Millikin (*8*).

Microscopic Structure of the Bark (*6*)

Young Bark

Epidermis. Consists of a layer of epidermal cells with scattered hairs. The free surface of epidermal cells is much thickened and cutinized.

Periderm. Appears in the young stem between the cortical region and epidermis.

Cortex. This region is narrow and composed mainly of cortex parenchyma in the young branch or stems. Some of the cortical cells may become lignified as the bark grows older.

Mature Bark

Periderm. Composed of 2-3 layers of phelloderm, a layer of phellogen, and 10-20 layers of phellem cells at different stages of development. Phellem cells are mainly thin-walled, uniform in thickness and suberized. On cross section, phellem cells are rectangular in shape, about 30-50 μm in tangential diameter and mostly about 20 μm in radial diameter. Hexagonal in shape on tangential section and variable from 30-50 μm in height. Phelloderm cells are about the same shape and size as those of phellem cells but are parenchymatous. Cells often contain tanniferous substance and small crystals.

Sieve Cells. Aligned in radial rows. Every 5-7 cells are interrupted by one or two parenchyma cells and by sclereid groups at the outer part of the secondary phloem. The cross sectional areas are nearly rectangular in shape and mostly about 15 μm and 30 μm in radial diameter and tangential diameter, respectively. The length of sieve cells is variable, from 1.85-4.45 mm long with a mean length of 3.16 mm. Sieve areas appear mainly on radial walls aligned in single vertical rows. They are oval to nearly orbicular in shape, about 10 μm in diameter. Connecting strands and definitive callus are distinct in those cells close to the cambial region. Sieve cells amount to 60% of the tissue elements of the secondary phloem.

Parenchyma. Strands are aligned in more or less continuous tangential lines. Newly developed cells are about the same shape and size as sieve cells on cross section, but are expanded conspicuously at the outer region of inner bark and the outer bark. Individual cells in a strand are about 70 μm high and variable in height. The total length of a strand is about the same as that of its adjacent sieve cells. Cells contain abundant tanniferous substance and styloid crystals with elongated lateral faces and pointed ends, quite similar to those in hard pine barks.

Sclereids. Distributed in small groups, appearing about 10-20 cells away from the cambium. A group of mature sclereids is usually about 500 μm in diameter and about 1-3 mm high. They are variable in shape and size and branched and twisted. Cell walls are thick, with distinct lamellate layers of secondary wall, simple pits, and narrow lumen. Cells often contain abundant resinous substances. Early-formed sclereids are more scattered than grouped. Sclereids amount to approximately 16% of the tissue elements of the secondary phloem.

Rays. Mainly uniseriate, mostly about 20 cells and 400 μm in height. Marginal erect cells or albuminous cells are conspicuous at rays close to the cambium. Rays at the outer bark are dilated.

Eastern hemlock has a bark structure generally like that of western hemlock.

Physical Properties of Wood

Specific gravity	Green volume	0.38
	Air-dry volume	0.40
	Oven-dry volume	0.43
Density, lb/cu ft (kg/cu m)	Green	50 (800)
	Air-dry	28 (448)
	Oven-dry	27 (432)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	24 (348)

Specific gravity initially decreases with increase in height of tree and then it increases in taller height classes (*9*).

Percent shrinkage, dried to 0% moisture content: r – 3.0, t – 6.8, v – 9.7.

Percent moisture content, when green

Green basis	42
Oven-dry basis	74

According to Clark and Gibbs (*10*), eastern hemlock showed regular seasonal rhythm in water content of the outer sapwood with lows in April-May and August-September.

Additional publications in this area include Maeglin (*11*), Pronin (*12*) and Wahlgren, *et al.* (*13,14*).

Physical Properties of Bark

Specific gravity green volume	Inner bark	0.40
	Outer bark	0.44
	Total bark	0.43
Density (100% moisture content)	Green weight/ green volume	0.87
Specific gravity oven-dry weight & volume (*15*)		0.51

Chemical Composition of Wood

Proximate Analyses

	F.P.L.	F.P.L.	F.P.L.	Clermont and Schwartz (*16*)
Lignin, %	34.8	34.2	32.7	29.56[a]
Holocellulose, %	–	–	–	71.4[b]
C. & B. cellulose, %	52.8	56.5	55.2	–
Alpha-cellulose, %	40.1	42.5	40.3	53.04[c]
Hemicellulose, %	–	–	–	12.51[a]
Ash, %	–	–	–	0.28
Pentosans, %	–	9.5	–	5.12
Acetyl, %	–	–	–	1.32
Methoxyl, %	–	–	–	5.67
Moisture content, %	–	–	–	7.64
Solubility in				
Alcohol-benzene, %	4.0	3.4	4.6	–
Ether, %	1.2	0.2	0.6	0.65
1% NaOH, %	12.8	11.7	12.4	13.7
Hot water, %	3.2	3.1	3.8	3.35
Cold water, %	–	–	–	2.20
Uronic anhydride, %	–	–	–	3.51
Pentosans, %	–	–	–	24.9[d]
Uronic anhydride, %	–	–	–	17.3[d]
Hexosans (by difference)	–	–	–	57.8[d]

[a]Corrected for ash.
[b]Corrected for ash, lignin and extractives.
[c]Corrected for ash and lignin.
[d]As % of moisture-free hemicelluloses.

Data on holocellulose and C. & B. cellulose are given by Van Beckum and Ritter (*17*). Mingle and Boubel (*18*) found an ash content of 2.5%. The Institute of Paper Chemistry (*19*) found alcohol-benzene extractives to be 3.7%.

Extractives. Conidendrin was reported (*20*); tannin is absent (*21*).

Other Information. Mingle and Boubel (*18*) found a carbon content of 53.6%; hydrogen, 5.8%; nitrogen, 0.2%; and oxygen, 37.9%.

Chemical Composition of Bark

Proximate Analyses

	Chang and Mitchell (*22*)	The Institute of Paper Chemistry Project 3212 Report 10	Millikin (*7*)
Ash, %	1.6	2.0	2.5
Soluble in			
Benzene, %	2.8	–	–
Alcohol-benzene, %	–	25.4	–
95% Alcohol, %	21.2	–	–
1% NaOH, %	24.6	–	–
Hot water, %	3.3	–	–
Methoxyl, %	3.61	–	–
Volatile, %	–	–	72.0
Fixed carbon, %	–	–	25.5
Calcium, %	–	0.5	–
Silica, %	–	0.12	–

Carbohydrates

	Chang and Mitchell (*22*)
Reducing sugars from extractive-free bark	
Glucose, %	67
Unknown substances, %	2
Galactose, %	3
Mannose, %	13
Arabinose, %	8
Xylose, %	7

Other Information. Milliken (7) found the content of carbon to be 53.6%; hydrogen, 5.8%; nitrogen, 0.2%; and oxygen, 37.9%. For information on elements in bark, see Harder and Einspahr (*23*).

Pulping

Kraft. The wood is readily reduced; yield is slightly low; pulps are darker than spruce, require more bleach, and are weaker (*24,25*). Small-dimensioned wood is used for unbleached pulp.

Magnefite. These pulps are superior to regular sulfite pulps (*26*).

Mechanical. The wood is readily reduced; the pulp is slightly reddish in color and somewhat brittle. It requires 50% more power than does white spruce (*24,25,27-30*).

Sulfite. The wood is fairly readily reduced. The pulp is less strong than spruce pulp and darker. It has a reddish-gray cast and is quite dirty when unbleached. It is fairly readily bleached and is more rapidly beaten. The yield is slightly low (*25,31*).

Other Information. The pulp is darker and usually weaker than spruce pulp; it is also difficult to bleach, and therefore it is not desirable for high-grade papers. The sulfite process is used more than sulfate. The pulp is used principally for newsprint and wrapping papers and to a lesser extent for book and printing papers. It is generally pulped by the sulfite process.

Utilization of Wood and Bark

Use properties of wood. Freshly cut hemlock has a sour odor, while seasoned wood is odorless. The wood is coarse, uneven in texture, and splinters easily when worked with tools. It is moderately light, moderately weak in bending strength, moderately strong in end compression, low in splitting resistance, and average in nail-holding ability. It is not decay resistant. The wood tends to separate parallel to the annual rings.

Calorific Value of Wood

BTU/lb (bone dry)	8885
kg cal/kg (bone dry)	4937

Calorific Value of Bark

Million of BTU/air-dry cord	17.9
Million of kg cal/air-dry cord	4.5
BTU/o.d. lb	9517
kg cal/kg	4890
BTU/ft^3	255,056
kg cal/cu m	1819

Chemical uses of wood. Hemlock oil from the steam distillation of needles and twigs is used as a perfume in greases and shoe blackings and for medicine.

Chemical uses of bark. Tannin is extracted from the bark.

Other uses of wood. About three-fourths of the lumber is used for light framing, sheathing, roofing and subflooring, while the remainder is used for boxes, crates, pallets, railroad car construction and repair, general millwork, and sign construction.

Literature Cited

1. Young, H. E.; Hoar, L.; Ashley, M. Tappi 48(8):466-9(1965).

2. Shepard, H. B.; Bailey, I. W. Proc. Soc. Am. For. 9:522-5(1914).

3. Fegel, A. C. N.Y. State Coll. For., Tech. Bull. No. 55, 1941, 20 p.

4. Britt, K. W. Tappi 48(1):7-11(1965).

5. Timell, T. E. Holz Roh- Werkstoff 30(7):267-73(1972).

6. Chang, Y.-P. TAPPI Monograph Series No. 14, 1954, 249 p.

7. Young, H. E. Forest Prod. J. 21(5):56-9(1971).

8. Millikin, D. E. Pulp Paper Mag. Can. 56(13):106-8(1955).

9. Okkonen, E. A.; Wahlgren, H. E.; Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).

10. Clark, J.; Gibbs, R. D. Can. J. Botany 35(2):219-53(1957).

11. Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-202, 1973, 40 p.

12. Pronin, D. USDA, Forest Serv. Res. Pap. FPL-161, 1971, 16 p.

13. Wahlgren, H. E.; Hart, A. C.; Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-61, 1966, 22 p.

14. Wahlgren, H. E.; Baker, G.; Maeglin, R. R.; Hart, A. C. USDA, Forest Serv. Res. Pap. FPL-95, 1968, 12 p.

15. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 42 p.

16. Clermont, L. P.; Schwartz, H. Pulp Paper Mag. Can. 52(13):103-5(Dec., 1951).

17. Van Beckum, W. G.; Ritter, G. J. Tech. Assoc. Papers 22:619(1939); Paper Trade J. 108(7):27(1939).

18. Mingle, J. G.; Bouble, R. W. Wood Sci. 1(1):29-36(July, 1968).

19. The Institute of Paper Chemistry, Project 3212, Report 10.

20. Erdtman, H. Svensk Papperstidn. 47:155(1944).

21. Russell, A. J. Am. Leather Chemists Assoc. 37:340(1942).

22. Chang, Y.-P.; Mitchell, R. L. Tappi 38(5):315-20(May, 1955).

23. Harder, M. L.; Einspahr, D. W. To be submitted to Tappi.

24. McGovern, J. N.; Schafer, E. R.; Martin, J. S. TAPPI Monograph No. 4:130(1947).

25. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485. May, 1927. 101 p.

26. Tomlinson, G. H.; Tomlinson, G. H., II; Bruyce, J. R.; Tuck, N. G. M. Pulp Paper Mag. Can. 59(C):247-52(Conv., 1958).

27. Running, K. D. Pulp Paper Mag. Can. 41(2):18(1940).

28. Thickens, J. H. USDA, Forest Serv. Bull., 1912. 29 p.

29. Thickens, J. H.; McNaughton, G. C. USDA, Bull. No. 343. 1916.

30. Wynne-Roberts, R. I. Tech. Assoc. Papers 20:258(1937); Paper Trade J. 104(6):46(Feb. 11, 1937).

31. Baum, M.; Bard, J. W.; Salvesen, J. R.; Brabender, G. J. Tech. Assoc. Papers 30:405(1947); Paper Trade J. 126(9):130(1948).

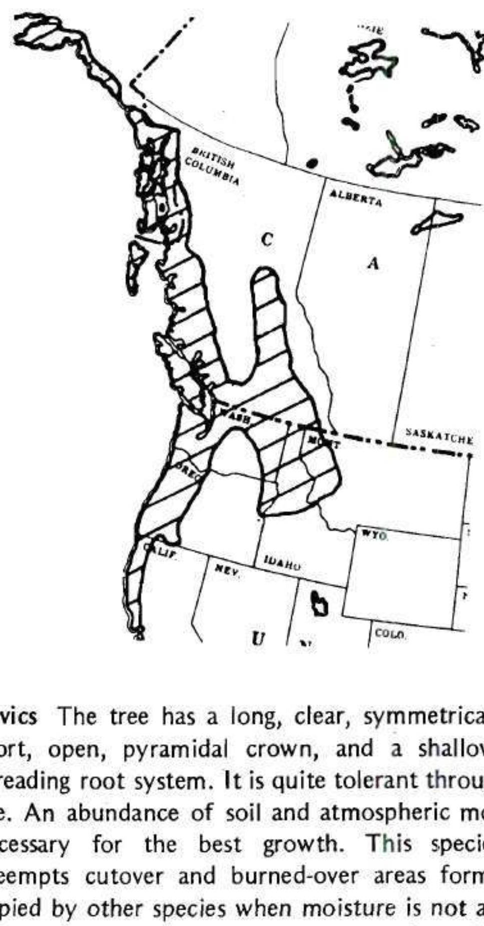
WESTERN HEMLOCK

Scientific Name *Tsuga heterophylla* (Raf.) Sarg.

Synonyms Pacific hemlock, west coast hemlock, hemlock.

Family Name Pinaceae.

Range Pacific Coast from the Alaskan Kenai Peninsula to northwestern California. Western hemlock also grows inland in northeastern Washington, northern Idaho, northwestern Montana and in the Selkirk Mountains of southeastern British Columbia at elevations below 5000 ft (1525 m). The western hemlock-Sitka spruce forest type totals about 10 million acres (4 million ha) in the United States.



Silvics The tree has a long, clear, symmetrical bole, a short, open, pyramidal crown, and a shallow, wide-spreading root system. It is quite tolerant throughout its life. An abundance of soil and atmospheric moisture is necessary for the best growth. This species often preempts cutover and burned-over areas formerly occupied by other species when moisture is not a limiting factor, because it is a constant and prolific seed producer. Western hemlock occurs in pure, dense, even-aged forests or as an occasional tree in mixed stands. Nearly pure, extensive forests of hemlock occur in southeastern Alaska, coastal British Columbia and western Washington. Its most common associates along the coast are Sitka spruce, western red-cedar, and Douglas-fir. Further inland, the spruce decreases and Alaska-cedar, grand, silver, noble, and subalpine firs, mountain hemlock, and western white pine may be found as minor elements in mixture, depending on the location. Douglas-fir with hemlock is a common type and makes up a considerable portion of the Douglas-fir region. The species is rated as very tolerant to low light and, ecologically, pure western hemlock stands are a climax type.

Tree Dimensions At 100 years, vigorous stands can contain trees that average 110-200 ft (33-60 m) in height and 16-23 inches (40-58 cm) in diameter. Under the best conditions, western hemlock will reach heights of 175-230 ft (53-70 m) and diameters of 35-48 inches (90-122 cm) at maturity.

Pathology Resistance to decay: low+

A number of tree trunk, butt and root rots including *Heterobasidion annosum, Phellinus pini, Phellinus* (*Poria*) *weirii, Echinodontium tinctorium,* and *Polyporus circinatus* cause considerable damage, especially in old-growth stands. Dwarf mistletoe (*Arceuthobium campylopodum*) is a common parasite that causes mortality in mature trees and reduces growth in trees of all sizes.

The western hemlock looper (*Lambdina fiscellaria lugubrosa*), the western blackheaded budworm, (*Acleris gloverana*), the western larch borer (*Tetropium velutinum*) and the hemlock sawfly (*Neodiprion tsugae*) are the most important insects that attack western hemlock. The western hemlock looper is periodically destructive, with outbreaks generally lasting about 3 years. The blackheaded budworm, another defoliator, usually builds up for 2-3 years, remains at a high level for 2-3 years and then decreases. The hemlock sawfly is an important defoliator in coastal forests while the larch borer attacks weakened and fire-scorched trees.

Gross Features of the Wood The sapwood, which is colored whitish to light yellowish brown, is usually not distinct from the heartwood. Frequently, the latewood shows a faint roseate, purplish or reddish-brown tinge. The texture is medium or fine and uniform, and the grain is usually straight. There is a distinct but not conspicuous growth ring. The wood is moderately hard, moderately light, odorless or sour when green, without characteristic taste. The earlywood usually occupies at least two-thirds of the growth ring and is lighter and less dense than the latewood. The transition from earlywood to latewood is more or less gradual. In the x-section the rays are very fine, not distinct with the unaided eye, and form a fine, close, inconspicuous fleck on the radial surface. Although resin canals are normally absent, longitudinal strands of traumatic resin canals or wound (traumatic) canals sometimes occur sporadically in tangential lines in widely separated growth rings. Longitudinal parenchyma cells are not visible.

Microscopic Structure of the Wood

Tracheids. Average 4.2 mm (1.8-6.0 mm) in length and 30-40 μm in diameter. Double wall thickness average 6.7 μm; weight factor (unbleached kraft) 1.00; coarseness 29 mg/100 m. Bordered pits in 1-2 (mostly 1) rows on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma small, quite uniform in size (piceoid to cupressoid), with distinct border, 1-4 (generally 2-3) per cross field; ray tracheid pits present. Volume occupied, approximately 91%.

Resin Canals. Normally absent.

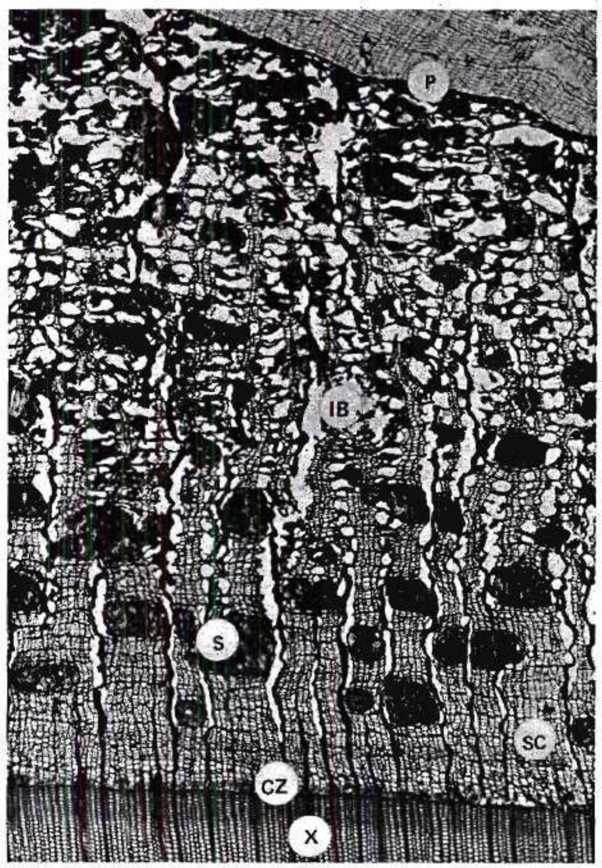
Rays. Uniseriate or very rarely biseriate, 1-16+ cells in height; ray tracheids present, usually restricted to one row on the upper and lower margins of the ray. Volume occupied, approximately 9%.

Longitudinal Parenchyma. Terminal and very sparse, or absent.

Gross Features of the Bark Mature western hemlock, bark, reddish-brown with a purplish-red hue where the periderm is exposed, is deeply fissured with rather large and firm scales. Inner bark, about 1/4-inch (0.6 cm) thick, has a yellowish hue when freshly cut, turning pink after exposure. Diffused sclereid groups, visible to the naked eye, begin very close to the cambium and occur throughout the inner bark. Western hemlock bark has long been recognized for its tannin yield and averages approximately 7% of the bole. Additional information in this area includes Chang (*1*).

Microscopic Structure of the Bark

Young Trees. Bark consists of an epidermis, periderm, narrow cortex and secondary phloem of sieve cells and phloem parenchyma. The epidermal cells have scattered hairs and often contain "resinous" substance. The phellem cells of the periderm are thin-walled and suberized. Cortex cells, thick-walled and collenchyma-like, are aligned compactly in more or less regular rows at the outer margin of the cortex. Some of the cortical cells may become "lignified" as the bark grows older. Scattered sclereids appear at the outer part of the secondary phloem which has the general arrangement of the mature bark. Intercellular resin passages appear distinctly only in young bark.



Cross section of western hemlock wood and bark. Elements depicted include xylem (X), cambium zone (CZ), sieve cells (SC), sclereids (S), and periderm (P). The inner bark (IB) is the area from the cambium zone to the periderm layer. Magnification 25X.

Mature Trees

Rhytidome. Usually 1/4-3/4 inch (0.6-1.9 cm) thick; composed of alternate layers of expanded parenchyma and sclereids isolated from the inner bark by successive bands of periderm.

Periderm. Consists of 2-3 layers of phelloderm, a layer of phellogen and 10-20+ layers of phellem. The thin-walled phellem cells are rectangular in cross section, usually about 20 μm in radial diameter, 30-50 μm in tangential diameter, and 20-50 μm in height. Phelloderm cells are slightly larger with comparatively thicker walls.

Secondary Phloem. Sieve cells, sclereids, parenchyma strands and uniseriate rays form the secondary phloem.

Phloem Fibers. None.

Sieve Cells. Aligned in radial rows of 3-7, are rectangular in cross section, 10-15 and 15-30 μm in radial and tangential dimensions, respectively, and vary from 1.5-4 mm in length. This shape is maintained only within approximately 20 cells of the cambial region. Beyond this area, the sieve cells become obliterated by the sclereid groups.

Sclereids. Diffused small groups of sclereids are distributed from close to the cambium throughout most of the inner bark. Individual cells in the sclereid groups are branched and twisted, about 400 μm long, and contain resinous substances.

Parenchyma. Interrupting the radially aligned sieve cells, parenchyma strands are aligned more or less in continuous tangential lines. Individual cells, when newly formed, are approximately the size and shape of sieve cells in cross section, but become radially expanded and enlarged nearer the outer bark.

Phloem Rays. Mainly uniseriate, are generally 10-15 cells high, approximately 300 μm, but may reach twice that height. Ray cells are 30-50 μm in radial dimension and about 10 μm high close to the cambium, but, like parenchyma, expand at the outer part of the inner bark. Marginal or albuminous cells, about 2-3 times the height of ordinary ray cells, are present at almost every ray close to the cambium.

Physical Properties of Wood

Specific gravity	Green volume	0.38
	Air-dry volume	0.42
	Oven-dry volume	0.44
Density, lb/cu ft (kg/cu m)	Green	41 (657)
	Air-dry	29 (464)
	Oven-dry	27 (432)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	24 (384)

Overall initial decrease in specific gravity with increase in height of tree, increasing slightly again in taller height classes (*2,3*).

Percent moisture content, when green

Green basis	42
Oven-dry basis	74

Percent moisture content oven-dry weight (*4*)

Heartwood	85
Sapwood	170

Percent shrinkage (*4*), dried to 20% moisture content: r – 1.4, t – 2.6, v – 4.0; dried to 6% moisture content: r – 3.4, t – 6.3, v – 9.5; dried to 0% moisture content: r – 4.3, t – 7.9, v – 11.9.

Additional information in this area includes: Kennedy and Swan (*5*), Krahmer (*6*) and Wellwood (*7*).

Physical Properties of Bark

Specific gravity green volume	Inner bark	0.46
	Outer bark	0.45
	Total bark	0.45
Specific gravity oven-dry weight & volume (*8*)		0.59
Density (100% moisture content	Green weight/ green volume	0.85
Moisture content, % o.d. (*9*)	Inner bark	134
	Outer bark	65

Chemical Composition of Wood

Proximate Analyses	F.P.L. (*10*)	F.P.L. Range of 8 Samples	Wise and Ratliff (*11*)	Ritter and Fleck (*12*) Sap.	Ritter and Fleck (*12*) Heart.	McGovern and Chidester (*13*) Sap.	McGovern and Chidester (*13*) Heart.
Lignin, %	27.8	28.9-31.2	30.40	31.82	30.3	28.8	29.5
Holocellulose, %	74.0	–	–	–	–	–	–
Cellulose, %	–	–	–	50.73	48.25	43.1	43.7
C. & B. cellulose, %	–	57.5-62.3	–	–	–	–	–
Alpha-cellulose, %	52.5	40.7-46.6	51.6	–	–	–	–
Hemicellulose, %	–	–	15.5	–	–	–	–
Ash, %	0.3	0.3	0.49	0.37	0.51	–	–
Pentosans							
Total, %	9.2	8.1-10.2	–	8.79	9.06	8.6	8.3
In cellulose, %	6.3	–	–	–	–	–	–

Mannan, %	–	–	4.1	–	–	–	–
Acetyl, %	–	–	1.21	1.83	1.73	–	–
Methoxyl, %	–	–	–	4.95	5.36	–	–
Xylan, %	–	–	7.30	–	–	–	–
CH_2 (from MeO not in lignin), %	–	–	0.16	–	–	–	–
Uronic anhydride, %	–	–	5.0	–	–	–	–

Extractives

Soluble in	F.P.L. (*10*)	F.P.L. Range of 8 Samples	Browning and Isenberg (*14*) Sap.	Heart.	Ritter and Fleck (*12*) Sap.	Heart.
Alcohol-benzene, %	1.6	1.9-4.1	1.6	4.6	2.1	5.8
Ether, %	0.8	0.3-1.3	0.8	1.0	0.34	0.70
1% NaOH, %	9.2	10.5-14.0	–	–	–	–
Hot-water, %	0.4	2.0-4.2	0.4	4.8	2.28	5.36
Cold-water, %	–	–	–	–	1.16	4.12

Additional information on extractives includes Lewis (*15*), Brauns (*16*), Benson (*17*), Anderson (*18*), Barton (*19-21*), and Polcin and Rapson (*22*).

Other Information

For information on fatty acids and resin acids, see Swan (*23*).

Chemical Composition of Bark

Analyses

	Weyer-haeuser (*24*)	Corder (*25*)	The Institute of Paper Chemistry Project 3212 Report 5
Hydrogen, %	5.8	–	–
Carbon, %	51.2	24.0	–
Oxygen, %	39.2	–	–
Nitrogen, %	0.1	–	–
Ash, %	3.7	0.2	1.7
Calcium, %	–	–	0.3
Silica, %	–	–	0.04
Volatile matter, %	–	74.3	–

For information on elements in bark, see Harder and Einspahr (*26*).

Extractives. The content of alcohol-benzene extractives was found by IPC to be 11.7%.

Pulping

Chlorine. This species can be chlorine-pulped with Cl, ClO_2, or hypochlorite, treated with ozone, and bleached with H_2O_2 and Na_2O_2 (*27*).

Kraft. The wood is readily reduced; yield normal; excellent strength and well balanced in burst and tear strength; dark on reddish side and offers no resistance to bleaching. Pretreatment with H_2S before pulping improves brightness and mechanical properties and gives pulps especially suitable for glassine and transparent papers and linerboards. Pretreatment with NaOH in addition to H_2S improves yield and quality.

H_2S-Kraft. This pulp can be used for linerboard (*28*). For kraft pulping information, see Kellogg and Thykeson (*29*) and Hatton and Keays (*30,31*). Gas-phase ozone treatment of kraft pulps improves brightness and some mechanical properties.

Magnefite. Bleached magnefite pulp is used for fine papers.

Mechanical. The wood is readily reduced; yields of 87% and 97% have been reported; the color is fair, and strength is standard; it requires 10-15% more power than spruce; it can be used in all places requiring groundwood. Groundwood from chips can be used for newsprint and for letterpress and offset printing papers (*32*); for mechanical properties, see Cochrane and Crotogino (*33*). For information on bleaching, see Wayman, *et al.* (*34*).

Nitric acid. Can be used for pulping.

NSSC. Requires high chemical and fiberizing energy; the pulp is good for paperboard [McGovern, *et al.* (*35*)].

Soda. Two-stage soda-oxygen pulps resemble kraft pulps; the yield is higher than with kraft pulping and produces duplex linerboards of better strength and brightness. H_2S treatment prior to soda pulping improves the yield.

Sulfite. Ammonia-, calcium-, and sodium-base pulps are used for dissolving pulps. Sodium sulfite-oxygen pulps are superior to kraft, soda, and alkaline sulfite pulps in yield, brightness, and bonding strength. NSSC pulping followed by oxygen and alkali treatment gives bleachable and linerboard grades of higher yield than kraft pulps and superior in some mechanical properties.

Sodium sulfite/oxygen pulps are superior to kraft, soda, and alkaline sulfite pulps in yield, brightness, and bonding strength. Duplex linerboards made from sodium sulfite/oxygen pulps were superior to conventional kraft linerboards in bursting strength, ring crush, and brightness.

Other Information. Additional information on pulping includes Cox and Worster (*36*), Fahey and Martin (*37*), Horn and Auchter (*38*), Marton and Leopold (*39*), Ruffini and Gandini (*40*), Vinje and Worster (*41*), Worster and Pudek (*42*), and Chidester, *et al.* (*43*). Sawdust can be refined (*44*).

Utilization of Wood and Bark

Use properties of wood. The wood is normally free from resin, light in color, takes a beautiful finish, holds nails and screws well, has high strength and high shrinkage, is seasoned well with care, pronounced silky sheen when dry, is easily worked, is satisfactorily glued.

Calorific Value of Wood

8500 BTU/lb
4723 kg cal/kg

Calorific Value of Bark

9799 BTU/lb
5444 kg cal/kg

262000 BTU/cu ft
1868 kg cal/m^3

Chemical uses of wood. Alcohol production: 54 gallons of 95% alcohol per ton by the Madison process.

Chemical uses of bark. A sodium carbonate extract of bark is used to make a binder for 3-layer wood particle boards (*45*).

Other uses of wood. Refined sawdust is used in newsprint along with groundwood and semibleached kraft pulp. Wood is used for slack cooperage for sugar and flour barrels. Forest residues are used for structural flakeboards.

Other uses of bark. Bark may be included in the furnish for hardboards. Bark removes heavy metal ions from solution. A bark derivative is used as a drilling mud additive.

Literature Cited

1. Chang, Y.-P. USDA, Tech. Bull No. 1095, 1954, 86 p.
2. Okkonen, E. A.; Wahlgren, H. E.; Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).
3. Farr, W. A. Wood Sci. 6(1):9-13(1973).
4. U.S. Forest Products Laboratory. Agriculture Handbook No. 72, 1974.
5. Kennedy, R. W.; Swann, G. W. Inform. Rep. For. Prod. Lab., Vancouver No. VP-X-50, 1969.
6. Krahmer, R. L. Tappi 49(5):227-9(1966).
7. Wellwood, R. W. J. Forestry 58(5):361-8(1960).
8. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 42 p.
9. Smith, J. H. G.; Kozak, A. Forest Prod. J. 21(2):38-40(1971).
10. Forest Products Laboratory. Unpublished data.
11. Wise, L. E.; Ratliff, E. K. Anal. Chem. 19:459(1947).
12. Ritter, G. J.; Fleck, L. C. Ind. Eng. Chem. 18:608-9(1926).
13. McGovern, J. N.; Chidester, G. H. Tech. Assoc. Papers 22:617-19(1939.

19. Barton, G. M. Wood Fiber 2(2):144-50(Summer, 1970).

20. Barton, G. M. Forest Prod. J. 18(5):76-80(May, 1968).

21. Barton, G. M. Tappi 56(5):115-18(May, 1973).

22. Polcin, J.; Rapson, W. H. Pulp Paper Mag. Can. 72(10):84-90(T324-30)(Oct. 1971).

14. Browning, B. L.; Isenberg, I. H. *In*: Wise, L. E. and Jahn, E. C. (eds.) Wood Chemistry, Vol. 2, p. 1259-77. New York: Reinhold Publ. Corp. 1952.

15. Lewis, H. F. Tappi 33:299(1950).

16. Brauns, F. E. J. Org. Chem. 10:211(1945).

17. Benson, H. K.; Jones, F. M. J. Ind. Eng. Chem. 9:1096(1917).

18. Anderson, E. J. Biol. Chem. 165:233(1946).

23. Swan, E. P. Can. Dept. For., Inform. Rept. VP-X-115, 24 p. Aug., 1973.

24. Weyerhaeuser Co. Waste Wood Utilization for Energy. An in-house document of the Fuels and Combustion Section of Weyerhaeuser Co., Tacoma, WA Oct., 1973.

25. Corder, S. E. Oregon State Univ., Forest Research Laboratory, Corvallis. Research Bulletin 14. 1973.

26. Harder, M. L.; Einspahr, D. W. To be submitted to Tappi.

27. Singh, R. P.; Scott Paper Co. Can. pat. 970,111.

28. Vinje, M. G.; Thomson, J. M.; Chow, W. M. Tappi 56(11):153-6(Nov., 1973).

29. Kellogg, R. M.; Thykeson, E. Tappi 58(4):131-5(April, 1975).

30. Hatton, J. V.; Keays, J. L. Pulp Paper Mag. Can. 71(11):123-32(T259-268)(June 5-19, 1970).

31. Hatton, J. V.; Keays, J. L. Pulp Paper Mag. Can. 74(1):79-87(T11-19)(Jan., 1973).

32. Morkved, L.; Larson, P. Tappi 52(8):1465-7(Aug., 1969).

33. Cochrane, J. A.; Crotogino, H. F. Pulp Paper Mag. Can. 66(7):T388-92(July, 1965).

34. Wayman, M.; Anderson, C. B.; Rapson, W. H. Pulp Paper Mag. Can. 69(9):51-60(T225-34)(May 3, 1968).

35. McGovern, J. N.; Keller, E. L.; Martin, J. S.; Kingsbury, R. M. USDA, Forest Prod. Lab. Rept. 1912 (Dec., 1951).

36. Cox. L. A.; Worster, H. E. Pulp Paper Mag. Can. 73(9):106-9(T250-3)(Sept., 1972).

37. Fahey, D. J.; Martin, J. S. Madison, WI U.S. Forest Prod. Lab. [Rept. 2200] April, 1961. 37 p.

38. Horn, R. A.; Auchter, R. J. Paper Trade J. 156(46):55-9(Nov. 6, 1972).

39. Marton, R.; Leopold, B. Appita 27(2):112-18 (Sept., 1973).

40. Ruffini, G.; Gandini, G. TAPPI Alk. Pulping Conf. (Houston, TX), Oct., 1971: p. 21-7.

41. Vinje, M. G.; Worster, H. E. Tappi 52(7):1341-5(July, 1969).

42. Worster, H. E.; Pudek, M. F. Tappi 57(3):138-41(March, 1974).

43. Chidester, G. H.; Laundrie, J. F.; Keller, E. L. Tappi 43(10):876-80(1960).

44. Nystrom, E. W.; Okell, R. H. Pulp Paper Mag. Can. 70(7):83-7(T96-100)(April 4, 1969).

45. Anderson, A. B.; Wong, A.; Wu, K.-T. Forest Prod. J. 25(3):45-8(March, 1975).

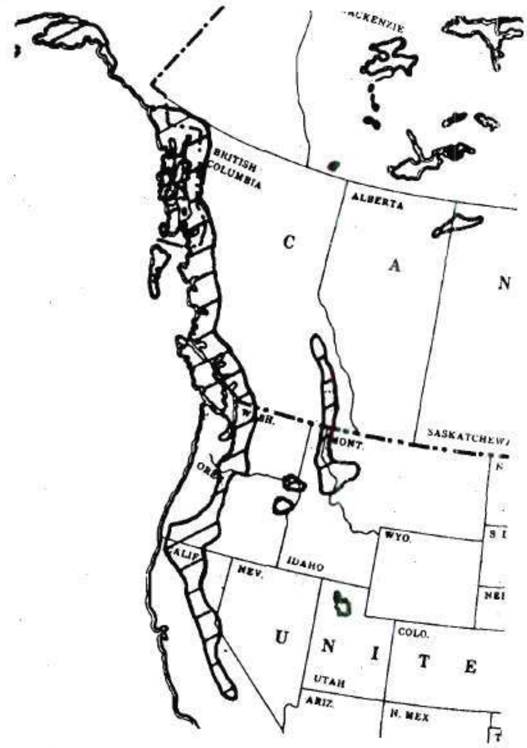
MOUNTAIN HEMLOCK

Scientific Name *Tsuga mertensiana* (Bong.) Carr.

Synonyms Black hemlock, alpine hemlock

Family Name Pinaceae

Range Southern Alaska to central California (latitude 61°40 ' to 36°40). Sea level (Alaska) to 10,000 ft (3050 m).



Silvics This large forest tree has a long, clear, or limby bole with a narrow, pyramidal crown of drooping or even pendulous branches. The root system is shallow. The best stands are found on moist slopes, flats, and heads of ravines with northerly exposure. Best development is in southern Oregon. Loose, coarse-textured, well-drained soils with sufficient moisture provide the best sites. In certain coniferous forests, mountain hemlock constitutes more than 75% of the stand. In parklike stands, the excessively tapered boles are the only species or are mingled with subalpine fir, Engelmann spruce, subalpine larch, and whitebark pine. Farther north, it occurs in mixture with Sitka spruce, western hemlock, Alaska-cedar, subalpine fir, and silver fir. This species is a prolific seed producer with heavy crops every few years. Mountain hemlock is rated as tolerant and may surpass all of its associates except western hemlock and silver fir in this respect.

Tree Dimensions 50-100 ft (15-30 m) tall and 10-20 inches (25-50 cm) in diameter. On the best sites, trees may reach 100-125 ft (30-38 m) in height and 30-40 inches (76-102 cm) in diameter.

Pathology Resistance to decay: low+

Trunk and butt rots attacking mountain hemlock include *Heterobasidion annosum, Phellinus pini, F. pinicola* and *Phaeolus schweinitzii*. Mountain hemlock sometimes has extensive heart rot but is generally sounder than associated western hemlock (*1*). The dwarf mistletoe attacking mountain hemlock is *Arceuthobium campylopodum* forma *tsugensis*.

The western blackheaded budworm (*Acleris gloverana*) at times defoliates mountain hemlock although it does not appear to be the preferred host. This is also true of the hemlock sawfly (*Neodiprion tsugae*). Killing weakened trees are the flatheaded fir borer (*Melanophila drummondi*) and the hemlock engraver (*Scolytus tsugae*). These insects, however, seldom kill any large numbers of trees.

Gross Features of the Wood The wood of mountain hemlock is moderately hard, fine and uniformly textured. The heartwood is a pale reddish brown and is usually not distinguishable from the moderately thin sapwood. The latewood is quite pronounced and is distinguishable from the lighter earlywood. In the x-section the rays are very fine, not distinct with the unaided eye, and form a fine, close, inconspicuous fleck on the radial surface. Resin canals are normally absent. Longitudinal parenchyma are not visible.

Microscopic Structure of the Wood

Tracheids. Average 2.0 mm in length and 25-45 µm in diameter. Bordered pits in 1-2 (mostly 1) rows on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma small, quite uniform in size (piceoid to cupressoid), with distinct border, 1-4 (usually 2-3) per cross field; ray tracheid pits present.

Resin Canals. Normally absent.

Rays. Uniseriate or very rarely biseriate, 1-16+ cells in height; ray tracheids present, usually restricted to one row on the upper and lower margins of the ray.

Longitudinal Parenchyma. Terminal and very sparse, or absent.

Gross Features of the Bark Dull purplish brown to reddish brown; divided into narrow, flattened ridges by deep, narrow fissures; up to 1.25 inches (3.2 cm) thick on old trees.

Physical Properties of Wood

Specific gravity	Green volume	0.43
	Air-dry volume	0.47
	Oven-dry volume	0.49
Density, lb/cu ft (kg/cu m)	Green	44 (700)
	Air-dry	33 (530)
	Oven-dry	31 (500)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	27 (430)

Percent shrinkage, dried to 0% moisture content (*2*): r – 4.4, t – 7.4, v – 11.4.

Percent moisture content, when green

Green basis	38
Oven-dry basis	62

Physical Properties of Bark

Specific gravity oven-dry weight & volume (*3*)	0.46

Chemical Composition of Wood

Proximate Analysis

	Martin (*4*)
Lignin, %	27.0
Holocellulose, %	59.8
Alpha-cellulose, %	42.6
Ash, %	0.5
Pentosans	
Total, %	7.0
In cellulose, %	7.4
Solubility in	
Alcohol-benzene, %	4.6
Ether, %	1.0
1% NaOH, %	11.6
Hot water, %	4.8

Extractives. Conidendrin has been reported (*5*).

Pulping

Kraft. The wood is readily reduced and strength is good (excellent burst and fair tear) (*4*).

Sulfite. The wood is readily reduced. It is slightly inferior to western hemlock in density, yield, and strength (both burst and tear) (*6*).

Utilization of Wood

Use properties of wood. The wood has a light color, high shrinkage, is easy to work, and can be glued satisfactorily.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 271, 1965, 762 p.
2. U.S. Forest Products Laboratory. Agriculture Handbook No. 72, 1974.
3. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969.
4. Martin, J. S. Tappi 32:534(1949).
5. Erdtman, H. Svensk Papperstidn. 47:155(1944).
6. Hatch, R. S.; Holzer, W. F. TAPPI Monograph No. 4:153(1947).

BALSAM FIR

Scientific Name *Abies balsamea* (L.) Mill.

Synonyms Balsam, Canada balsam, eastern fir

Family Name Pinaceae

Range Newfoundland west to Alberta in Canada, Lake States, Northeast, and Appalachians. Sea level to about 5000 ft (1524 m). The spruce-fir type covers nearly 11 million acres (4.5 million ha) in New England and New York (*1*) and 3 million acres (1.2 million ha) in the Lake States (*2*).

Pathology Resistance to decay: low

The shoestring fungus, *Armillariella mellea* is considered by many to be the only important killing disease of balsam fir in the United States. Other rots of balsam fir include the brown cubical rots, *Polyporus balsameus* and *Coniophora puteana*. White stringy rots affecting balsam fir include *Corticium galactinum, Odontia bicolor* and *Poria subacida*. The main trunk rot of balsam fir is the red heart fungus, *Stereum sanguinolentum*. This fungus enters almost entirely through injuries to the trunk.

Silvics This small to medium-sized tree has a moderately tapering bole, a dense, narrow, pyramidal crown terminating in a spirelike tip, and a shallow, widespreading root system. Abundant moisture is necessary for best development. In swamps it often forms pure stands but does best in association with spruce on the adjacent flats which are better drained. On upland sites it occurs in mixture with spruce, hemlock, birch, beech, and maple. In the Lake States, balsam fir is often found in mixture with aspen, paper birch, and white spruce on highlands. Good seed crops occur every 2-4 years with light crops during intervening years. The species is rated as tolerant.

Tree Dimensions 40-60 ft (12-18 m) tall and 12-18 inches (30-46 cm) in diameter.

The two most important insect enemies of balsam fir are the spruce budworm (*Choristoneura fumiferana*) and the balsam woolly aphid (*Adelges piceae*). Despite its name, the spruce budworm prefers fir and can cause heavy damage to stands that contain a high proportion of balsam fir. Trees suffering a heavy attack of the balsam woolly aphid can be killed in 3-4 years. Serious defoliators of balsam fir include the eastern hemlock looper (*Lambdina fiscellaria fiscellaria*) and the black-headed budworm (*Acleris variana*).

Balsam fir is very susceptible to fire damage and windthrow.

Gross Features of the Wood The wood of this species cannot be distinguished from that of the other true firs. The sapwood is whitish to creamy white or pale brown (especially the earlywood), the latewood frequently has a lavender tinge, and the heartwood is not distinct. The wood is soft, weak, dull, light, without characteristic odor or taste. It is medium textured and straight and even-grained. Flat grain boards exhibit a distinct but not conspicuous growth ring figure. The earlywood usually occupies two-thirds or more of the growth ring; the transition from earlywood to latewood is very gradual, but the latewood zone is distinct with the unaided eye. In the x-section the rays are very fine and are not distinct with the unaided eye. A fine, close, inconspicuous fleck is formed by the rays on the radial surface. Normal resin canals are absent, but traumatic (wound) canals are sometimes present; if so, they are sporadic and arranged in a tangential row which frequently extends for some distance along the growth ring, appearing as dark streaks along the grain. Longitudinal parenchyma cells are not visible. Young, *et al.* (*3*) discuss the weight of wood substance for components of balsam fir. Weights and centers of gravity for balsam fir are covered by Steinhilb and Erickson (*4*).

Microscopic Structure of the Wood

Tracheids. Average 3.5 mm (1.9-5.6 mm) in length and 30-40 μm in diameter. Moderately thick fiber walls. Weight factor (unbleached kraft) of 0.85. Bordered pits in one row or very rarely paired on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma small, quite uniform in size (taxodioid), with distinct border, 1-3 (generally 2-3) per cross- field; ray tracheid pits sometimes present. Volume occupied, approximately 94%. Fegel (*5*) found root tracheids to average 2.1 mm. Information on fiber coarseness can be found in Britt (*6*).

Resin Canals. Normally absent.

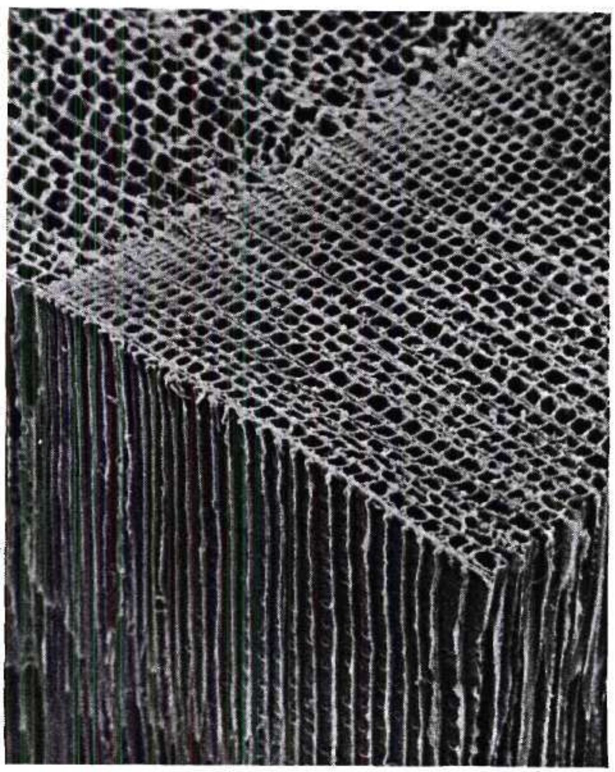
Rays. Uniseriate, very variable in height from 1-30+ cells, and made up wholly of ray parenchyma or rarely with a row of ray tracheids on both margins. Volume occupied, approximately 6%.

Longitudinal Parenchyma. Terminal and very sparse, or absent.

Gross Features of the Bark On young trees and the upper part of old trees, balsam fir bark is dull green with grayish patches and smooth except for numerous raised resin blisters. With age, the bark breaks up into small, reddish-brown, irregular thin scales and the blisters usually become dried. Comparatively thin, trees at age 30 usually have a bark thickness of 0.2-0.3 inch (0.51-0.76 cm) at breast height (*7*). Trees grown in favorable conditions or of greater age may have barks up to 0.5 inch (1.3 cm) or more thick. In cross section, the smooth outer bark of average age trees usually has one layer of light yellowish-brown periderm or cork, a cortical region with pronounced blister pockets, and a broad secondary phloem region occupying about 1/2 to 3/4 of the total bark thickness. Due to the persistent cortex and continuously developing periderm, rhytidome may not form until the tree is very old and/or only at the basal portion of the trunk. According to Young (*8*), the bark of various components as a percent of the complete tree bark amounted to: branches and unmerchantable top – 29%, merchantable bole – 41%, and stump and roots – 30%. Additional publications on bark percentages and thickness are Hale (*9*) and Marden, *et al.* (*10*).

Microscopic Structure of the Bark

Balsam fir bark of approximately 30-year-old trees is composed of the same three regions, periderm, cortex, and secondary phloem, as a young stem. Differences are only in the proportional widths of the zones and the increase in sclereids or lignified cells with age.



Scanning electron micrograph of balsam fir, showing all three planes (cross sectional, radial and rangential). Magnification 90X.

Periderm. Consists of one layer of phellogen, 2-3 layers of regularly aligned and generally compact phelloderm which merges with the cortex, and variable layers of thin-walled phellem or cork cells.

Cortex. The broadest region in young branches and stems, the cortex is composed of parenchyma type cells aligned rather regularly in more or less tangential lines at the outer bark. Some cells become enlarged and, as the tree ages, some become lignified and form small sclereid groups. In the middle of the cortex of the young tree are always 1-2 layers of resin canals that later enlarge to form the "blister pockets." They are aligned in more or less tangential rows and some open to the outer surface of the bark.

Inner Bark. Consists of radially aligned sieve cells and phloem rays, interspersed with parenchyma, resin passages and sclereid groups.

Sieve Cells. Rectangular in cross section and varying from 20-35 µm and 10-30 µm in tangential and radial dimensions, respectively, sieve cells have an average length of 1.5-2.2 mm (*7*). Usually 5-9 cells are aligned between two more or less tangential rows of parenchyma. According to Chang (*7*), sieve cells amount to 54.8% of the tissue elements of the secondary phloem.

Parenchyma. Phloem parenchyma usually appear in single layers but are sometimes sporadic. A strand is generally about the same length as the adjacent sieve cells. The thin-walled parenchyma cells, containing a tanniferous substance and single calcium oxalate crystals, are approximately the same as the sieve cells on cross section but often are radially expanded.

Sclereids. Parenchyma and ray cells are the origin of the phloem sclereids. Cell walls become "lignified" and very thick and individual cells often lose their original shape, becoming branched and twisted and forming groups of often 20 or more.

Rays. Phloem rays, generally uniseriate, are usually 10-20 cells or 200-300 µm high. Erect ray marginal or albuminous cells, in single or occasionally double rows, are present on rays close to the cambial zone. From these cells, the resin cells originate. "Resinous" droplets in the protoplasm disintegrate the cell nucleus, and, as the content increases, obliterate the original protoplasm, burst through the cell wall and form a new resin passage. As the resin flows through, adjacent phloem tissues are also often obliterated and the cell walls broken. These resin passages, vertical or irregular, are without border cells. As the tree ages, sieve cells at the outer part of the inner bark become obliterated or lignified and resin passages and sclereid groups increase in the secondary phloem and often appear in the late-formed rhytidome of the balsam fir.

Physical Properties of Wood

Specific gravity	Green volume	0.34
	Air-dry volume	0.36
	Oven-dry volume	0.37
Density, lb/cu ft (kg/cu m)	Green	45 (721)
	Air-dry	25 (400)
	Oven-dry	23 (368)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	21 (336)

Initial decrease in specific gravity with increase in height of tree and then increase in taller height classes (*11*).

According to Thor and Barnett (*12*), no regional variation pattern was evident for wood specific gravity or tracheid length in the southern Appalachians.

Mean specific gravity was approximately 6% higher in unfertilized trees than fertilized trees (*13*).

Percent shrinkage, dried to 0% moisture content: r – 2.9, t – 6.6, v – 11.2.

Percent moisture content, when green

Green basis	54
Oven-dry basis	117

Additional information in this area includes Bendtsen (*14*), Besley (*15*), Clark and Gibbs (*16*), Erickson (*17*), Maeglin (*18*), Marden, *et al.* (*10*), Pronin (*19*), Wahlgren, *et al.* (*20-21*), and Heger (*22,23*).

Physical Properties of Bark

Specific gravity green volume	Inner bark	0.32
	Outer bark	0.46
	Total bark	0.40
Density (100% moisture content)	Green weight/ green volume	1.07
Specific gravity oven-dry weight & volume (*24*)		0.63

Additional information in this area includes Hale (*9*), and Marden, *et al.* (*10*).

Chemical Composition of Wood

Proximate Analyses

	Lauer and Youtz (*25*)	Fengel and Grosser (*26*)		Young (*27*)	Clermont and Schwartz (*28*)	Cote *et al.* (*29*)[d] normal wood	compression wood
Lignin, %	31.3	27.70	29.4	29.4	27.70[a]	29.9	40.1
Holocellulose, %	–	70.0	70.28	–	70.0[b]	–	–
C. & B. cellulose, %	56.2	–	–	–	–	–	–
Alpha-cellulose, %	–	–	–	–	49.41[c]	–	–
Hemicellulose, %	–	–	–	–	15.41[a]	–	–
Ash, %	0.54	0.40	0.2	0.2	0.40	0.3	0.4
Pentosans, %	–	6.97	5.3	–	6.97	–	–
Mannan, %	–	–	–	12.4	–	–	–
Acetyl, %	–	1.52	1.5	1.5	1.52	1.3	0.9
Methoxyl, %	–	5.47	–	–	5.47	–	–
Moisture content, %	–	–	–	–	6.62	–	–
Solubility in							
Alcohol-benzene, %	1.15	4.25	–	–	4.25	–	–
Ether, %	0.20	1.80	–	–	1.80	–	–
1% NaOH, %	12.6	–	–	–	13.4	–	–
Hot water, %	3.65	3.59	–	–	3.59	–	–
Hot water extraction of residue from alcohol-benzene extraction, %	–	–	–	–	0.39	–	–
Cold water, %	–	2.7	–	–	2.70	–	–
Uronic anhydride, %	–	–	–	3.4	3.84	5.5	3.8
Pentosans, %	–	–	–	–	31.9[d]	–	–
Uronic anhydride, %	–	–	–	–	16.1[d]	–	–
Hexosans (by difference), %	–	–	–	–	52.0[d]	–	–
Cellulose, %	–	49.41	44.8	47.7[e]	–	–	–
Polyoses, %	–	22.74	–	–	–	–	–

[a]Corrected for ash.
[b]Corrected for ash, lignin, and extractives.
[c]Corrected for ash and lignin.
[d]In moisture-free hemicelluloses.
[e]Based on extractive-free wood.

Barnes (*30*) found alcohol-benzene solubles to be 2.2-2.9% and ether solubles to be 0.9-1.2%.

Richter (*31*) reported analyses of sapwood and heartwood of a July-felled tree and a February-felled tree. Data on holocellulose and C. & B. cellulose are presented by Hajny and Ritter (*32*).

Rapson *et al.* (*33*) found the ash content of dry wood to be 0.46%.

Carbohydrates. Young (*27*) found the galactan content to be 1.0%; glucan, 46.8%; araban, 0.5%; and xylan, 4.8%.

Residues of	Cote *et al.* (*29*) normal wood	compression wood
Galactose	1.4	7.6
Glucose	44.6	31.6
Mannose	10.0	6.3
Arabinose	1.6	1.8
Xylose	5.4	7.5

Extractives. For percent composition of extractives and yield, see Drew and Pylant (*34*). For extractives in heartwood, see Swan (*35*) and Zavarin and Snajberk (*36*).

Other Information. Bowers *et al.* (*37*) found juvabione. Young (*8*) reports the percent of elements.

Chemical Composition of Bark

Proximate Analyses

	Chang and Mitchell (*38*)	Milliken (*39*)	The Institute of Paper Chemistry Project 3212 Report 5
Ash, %	2.3	2.6	3.4
Solubility in			
Alcohol-benzene, %	–	–	19.5
Alcohol, %	3.3	–	–
Benzene, %	13.2	–	–
1% NaOH, %	30.6	–	–
Hot water, %	2.7	–	–
Calcium, %	1.0	–	–
Silica, %	0.1	–	–

Percent moisture content, when green (*17*) 54.8

Carbohydrates

	Chang and Mitchell (*38*)
Reducing sugars in extractive-free bark	
Glucose, %	64
Unknown substances, %	3
Galactose, %	5
Mannose, %	12
Arabinose, %	9
Xylose, %	7

Other Information. Corder (*40*) found the dry weight of bark to be composed of 52.8% carbon, 6.1% hydrogen, and 38.8% oxygen and nitrogen. Young (*8*) reports the essential elements in bark of various parts of the tree. For additional information on elements in bark, see Harder and Einspahr (*41*).

Pulping

Bisulfite. The wood can be pulped by bisulfite-acid sulfite and neutral sulfite-acid sulfite methods and bleached with hydrogen peroxide and sodium hydrosulfite. For information on high-yield pulps by the sodium bisulfite process, see Horn and Simmonds (*42*).

Groundwood. Refiner mechacal pulp from chips can be bleached in a two-stage process with hypochlorite and peroxide. Groundwood can also be bleached with ZnS_2O_4 or H_2O_2; a two-stage process of H_2O_2 followed by ZnS_2O_4 gives brightness of 73.

Kraft. The wood is readily reduced, yield is normal, the pulp is easily bleached, and strength is equal to that of spruce (*43,44*). For kraft pulping information, see Gagnon and Hunt (*45*) and Hatton (*46*). Chips can be pulped to a permanganate number of 16.5-20.9 for bleachable grades and 28.6 for brown paper grades; the pulp can be bleached to a brightness of about 90% by a 5-stage chlorine-chlorine dioxide sequence (*47*). Pulps can be bleached by a DEH or D/CEH sequence (*48*). Polysulfide added to kraft liquor increases the yield (*49*).

Magnefite. For physical and mechanical properties, see reference (*50*).

Mechanical. The wood is readily reduced, and the yield is 89%. The pulp has excellent color and strength, equivalent to spruces. It requires 10-15% less power than spruce (*44,51,52*).

Neutral Sulfite. Burst and tear strength and breaking length are given for pulps having a brightness of GE 50-53% (*53*).

Neutral Sulfite Semichemical. Maximum values in burst, tear, and tensile strengths were found at yields of 50-60%; more chemical is consumed than in kraft pulping (*54*).

Oxygen. Oxygen pulping with sodium borate or NaOH gives a higher yield than does kraft pulping; for pulp properties, see Minor and Sanyer (*55*).

Sulfite. The wood is reduced quite readily but not so easily as the spruces. Color is good, and pulp is equal to spruce in all strength characteristics except folding endurance, which is somewhat lower. The yield is normal. The pulp is readily bleached. It is used for newsprint, wrapping and book papers and high-grade printing papers (*43,44,56-59*). Year-old dead wood can be pulped by the sulfite process. For information on 2-stage sulfite pulping, see Sanyer *et al.* (*60*).

Thermomechanical. The wood is used with *Picea mariana* for thermomechanical pulps.

Other Information. The wood is pulped by all pulping processes. Pitch has caused some difficulty with the groundwood process. Its low density causes low yield of pulp per cord compared with other woods. Semichemical pulp is used for book papers. The most important use of balsam fir is for pulp.

Utilization of Wood and Bark

Use properties of wood. The wood is soft, light in weight and color, low in bend and compression strength, and low in ability to resist shock. It shrinks only moderately in drying and is easy to season. It is low in nail-holding ability. It has no taste or odor when seasoned.

Calorific Value of Wood

Million of BTU/air-dry cord	15.5
Million of kg cal/air-dry cord	3.9

Calorific Value of Bark

BTU/lb	9339
k cal/kg	5189
BTU/ft^3	233475
k cal/cu m	1665

Chemical uses of bark

Oleoresin is used as a medium for permanent mounting of microscopic specimens and as a cement for various parts of optical systems. Canada balsam is widely used for medicinal purposes.

Other uses of wood. It is used for dry-formed hardboard. The pulp is used for storage battery separators.

Other uses of bark. The inner bark is milled and added to bread.

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 445, 1973, 114 p.
2. Ohmann, L. F.; Batzer, H. O.; Buech, R. R.; Lothner, D. C.; Perala, D. A.; Schipper, A. L., Jr.; Verry, E. S. USDA, forest Serv. Gen. Tech. Rept. NC-48, 1978, 34 p.
3. Young, H. E.; Hoar, L.; Ashley, M. Tappi 48(8):466-9(1965).
4. Steinhilb, H. M.; Erickson, J. R. USDA, Forest Serv. Res. Pap. NC-75, 1972, 7 p.
5. Fegel, A. C. N.Y. State Coll. For., Tech. Bull. No. 55, 1941, 20 p.
6. Britt, K. W. Tappi 48(1):7-11(1965).
7. Chang, Y.-P. TAPPI Monograph Series No. 14, 1954, 249 p.
8. Young, H. E. Forest Prod. J. 21(5):56-9(1971).
9. Hale, J. D. Pulp Paper Mag. Can. 56(13):113-17(1955).
10. Marden, R. M.; Lothner, D. C.; Kallio, E. USDA. Forest Serv. Res. Pap. NC-114, 1975, 9 p.
11. Okkonen, E. A.; Wahlgren, H. E.; Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).
12. Thor, E.; Barnett, P. E. Forest Sci. 20(1):32-40(1974).
13. Gagnon, J. D.; Hunt, K. Can. J. For. Res. 5(3):399-402(1975).
14. Bendtsen, B. A. USDA, Forest Serv. Res. Pap. FPL-237, 1974, 28 p.
15. Besley, L. Pulp Paper Res. Inst. Can., Tech. Rept. No. 489 (Woodlands Res. Index No. 182), 1966, 30 p.
16. Clark, J.; Gibbs, R. D. Can. J. Bot. 35(2):219-53(1957).
17. Erickson, J. R. USDA, Forest Serv. Res. Note NC-141, 1972, 3 p.
18. Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-202, 1973, 40 p.
19. Pronin, D. USDA, Forest Serv. Res. Pap. FPL-161, 1971, 16 p.
20. Wahlgren, H. E.; Hart, A. C.; Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-61, 1966, 22 p.

21. Wahlgren, H. E.; Baker, G.; Maeglin, R. R.; Hart, A. C. USDA, Forest Serv. Res. Pap. FPL-95, 1968, 12 p.

22. Heger, L. Can. J. For. Res. 4(4):477-81(1974).

23. Heger, L. Can. J. For. Res. 4(3):321-6(1974).

24. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 42 p.

25. Lauer, B. E.; Youtz, M. A. Tech. Assoc. Papers 15:255(1933); Paper Trade J. 96(3):36(Jan. 19, 1933).

26. Fengel, D.; Grosser, D. Holz Roh- Werkstoff 33:32-4(1975).

27. Young, H. E. Personal communication.

28. Clermont, L. P.; Schwartz, H. Pulp Paper Mag. Can. 52(13):103-5(Dec., 1951).

29. Cote, W. A., Jr.; Pickard, P. A.; Timell, T. E. Tappi 50(7):350-6(July, 1967).

30. Barnes, F. Chem. Met. Eng. 28:503(1923).

31. Richter, G. A. Ind. Eng. Chem. 33:78(1941).

32. Hajny, G. J.; Ritter, G. J. Tech. Assoc. Papers 25:595(1942); Paper Trade J. 113(13):83(Sept. 25, 1941).

33. Rapson, W. H.; Wayman, M.; Anderson, C. B. Pulp Paper Mag. Can. 66(5):T255-71(May, 1965).

34. Drew, J.; Pylant, G. D., Jr. Tappi 49(10):430-8 (Oct., 1966).

35. Swan, E. P. Can. J. Chem. 45(13):1588-90(July 1, 1967).

36. Zavarin, E.; Snajberk, K. Phytochem. 4(1):141-8(Feb., 1965).

37. Bowers, W. S.; Fales, H. M.; Thompson, M. J.; Uebel, E. C. Science 154(3752):1020-1(Nov. 25, 1966).

38. Chang, Y.-P.; Mitchell, R. L. Tappi 38(5):315-20(May, 1955).

39. Milliken, D. E. Pulp Paper Mag. Can. 56(13):106-8(1955).

40. Corder, S. E. Properties and uses of bark as an energy source. XVI IUFRO World Congress, Oslo, Norway. June 20-July 2, 1976, Research Paper 31.

41. Harder, M. L.; Einspahr, D. W. To be submitted to Tappi.

42. Horn, R. A.; Simmonds, F. A. Tappi 51(1):67-73A(Jan., 1968).

43. McGovern, N. H.; Schafer, E. R.; Martin, J. S. TAPPI Monograph No. 4:130(1947).

44. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485. May, 1927. 101 p.

45. Gagnon, J. D.; Hunt, K. Can. J. For. Res. 5(3):399-402(Sept., 1975).

46. Hatton, J. V. Tappi 59(8):48-50(Aug., 1976).

47. Laundrie, J. F.; Hyttinen, A. Sulfate pulping of balsam fir. Madison, WI, U.S. Forest Prod. Lab. (Rept. 2225). July, 1961. 7 p.

48. Hatton, J. V.; Eade, B. Pulp Paper Mag. Can. 68(9):T420-30(Sept., 1967).

49. Sanyer, N.; Laundrie, J. F. Tappi 47(10):640-52(Oct., 1964).

50. de Montmorency, W. H. Pulp Paper Mag. Can. 67(9):T399-406(Sept., 1966).

51. Thickens, J. H.; McNaughton, G. C. USDA, Bull. No. 343. 1916.

52. Wynne-Roberts, R. I. Tech. Assoc. Papers 20:258(1937); Paper Trade J. 104(6):46(Feb. 11, 1937).

53. Chidester, G. H.; Laundrie, J. F.; Keller, E. L. Tappi 43(10):876-80(Oct., 1960); Paper Trade J. 144(29):51-2(July 18, 1960).

54. McGovern, J. N.; Keller, E. L. Pulp Paper Mag. Can. 49(9):93(1948).

55. Minor, J. L.; Sanyer, N. Tappi 57(5):120-2(May, 1974).

56. Johnsen, B.; Reese, C. H. Tech. Assoc. Papers 14:326(1931); Paper Trade J. 91(11):66(Sept. 11, 1930).

57. Richter, G. A. Ind. Eng. Chem. 33:532(1941).

58. Schur, M. O.; Baker, R. E. Tech. Assoc. Papers 25:453(1942); Paper Trade J. 115(12):33(Sept. 17, 1942).

59. Schur, M. O.; Ingalls, E. G. Tech. Assoc. Papers 26:296(1943); Paper Trade J. 117(12):34(1943).

60. Sanyer, N.; Keller, E. L.; Chidester, G. H. Tappi 45(2):90-104(Feb., 1962).

WHITE FIR

Scientific Name *Abies concolor* (Gord. & Glend.) Lindl.

Synonyms Concolor fir, silver fir, white balsam, balsam fir

Family Name Pinaceae

Range Widely distributed in the Rocky Mountains and Pacific Coast regions, extending from New Mexico and Colorado westward to Oregon and California, with the best development attained in California and southwestern Oregon. White fir is found at varying altitudes, growing at elevations as low as 2000 ft (610 m) in the Oregon Willamette Valley and up to 11,000 ft (3350 m) in the southern Rockies. In the interior parts of its range, white fir grows at 6,000-11,000 ft (1830-3350 m) in elevation but most frequently at 6900-8900 ft (2100-2700 m).

Silvics The tree has a long, clear, slightly tapering bole, a domelike crown unless malformed by mistletoe, and a shallow, wide-spreading root system. Best development is on deep, rich, moist, well-drained, gravelly, or well-drained sandy loam slopes and benches with a northerly exposure, but it will survive on dry barren sites. This species is usually in mixture with other conifers, principally sugar, ponderosa, Jeffrey, and limber pines, incense-cedar, Douglas-fir, giant sequoia, subalpine fir, and Engelmann spruce and sometimes constitutes as much as 80% of the stand in parts of the Sierra Nevada. Good seed crops occur at about 5-year intervals. White fir is rated as tolerant to very tolerant.

Tree Dimensions Sierra Nevada – 130-150 ft (40-46 m) tall and 3-4 ft (91-122 cm) in diameter. Rockies – 80-100 ft (24-30 m) tall and 15-30 inches (38-76 cm) in diameter.

Pathology Resistance to decay: low

Heart and butt rot fungi damage white fir extensively, with the principal trunk rot on the coast being *Echinodontium tinctorium*. Other butt rot fungi, which often gain entry through fire scars, basal wounds, branch stubs, broken stops and open knots include *Heterobasidion annosum, Pholiota adiposa* and *Armillariella mellea*. Often found in white fir, causing deformed crowns and serving to introduce decay are fir mistletoe (*Phoradendron pauciflorum*) and the fir dwarf mistletoe (*Arceuthobium campylopodum* forma *abietinum*).

The Douglas-fir tussock moth (*Orgyia pseudotsugata*) is a defoliator of major importance in the true fir forests. Outbreaks reach epidemic proportions but subside dramatically after about three years. The western spruce budworm (*Choristoneura occidentalis*) is the most destructive forest defoliator in western North America (*1*). Some outbreaks flare up and subside within a relatively short period of time while others last for many years. The fir engraver beetle (*Scolytus ventralis*) causes severe damage to white fir, particularly in California and Oregon. There are a number of other species of *Scolytus* which also attack white fir.

Gross Features of the Wood The wood of the western true firs is whitish to light buff to yellowish brown or light brown, the latewood frequently with a roseate, reddish-brown, or lavender tinge. Sapwood and heartwood are not distinguishable. The wood is moderately soft, light, generally straight and even-grained, medium and fairly uniformly textured, without characteristic taste or odor if dry, but sometimes with a slight disagreeable odor when green. The earlywood occupies at least one-half of the growth ring; the transition to latewood is gradual, but the latewood is very distinct. In x-section the rays are very fine and are not distinct without magnification. In radial surface they form a fine, close, inconspicuous fleck. Normal resin canals are absent, but traumatic (wound) canals are sometimes present; if so, they are sporadic and arranged in a tangential row which frequently extends for some distance along the ring, appearing as dark streaks along the grain. Longitudinal parenchyma cells are not visible.

Microscopic Structure of the Wood

Tracheids. Average 3.4 mm in length and 35-45 μm in diameter. Weight factor (unbleached kraft) approximately 0.95 and coarseness approximately 24 mg/100 m. Bordered pits in one row or occasionally paired on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma small, quite uniform in size (taxodioid), 1-4 (generally 2-4) per cross-field; ray tracheid pits absent. The length of tracheids varies directly with distance from the pith. This relationship is independent of height, provided the cross section is somewhat above ground (*2*).

Rays. Uniseriate, very variable in height ranging from 1-30+ cells, consisting entirely of ray parenchyma.

Longitudinal Parenchyma. Terminal and sparse, or absent.

Gross Features of the Bark Thickness is 4-7 inches (10-18 cm) on old stems, ash gray and divided by deep irregular furrows into thick, horny flattened ridges; young stems have conspicuous resin blisters. The periderm of white fir has a yellowish hue and is much lighter in color than the periderm of grand fir. Zobel (*3*) describes a chimera of red and yellow periderm color from a tree in a population intermediate between *A. concolor* and *A. grandis.*

Microscopic Structure of the Bark (*4*)

Sieve Cells. Arranged in short radial rows and shorter than those of most of the genera.

Phloem Fibers. None

Sclereids. Abundant sclereid groups, aligned more or less in discontinuous tangential lines. Sclereids short, branched and twisted.

Parenchyma. Containing abundant isodiametric crystals.

Rays. Fusiform rays lacking.

Physical Properties of Wood

Specific gravity	Green volume	0.35
	Air-dry volume	0.37
	Oven-dry volume	0.39
Density, lb/cu ft (kg/cu m)	Green	47 (753)
	Air-dry	26 (416)
	Oven-dry	24 (384)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	22 (352)

Percent shrinkage, dried to 0% moisture content: r – 3.3, t – 7.0, v – 9.8.

Percent moisture content, when green	
Green basis	52
Oven-dry basis	110

Percent moisture content oven-dry basis (*5*)	
Heartwood	98
Sapwood	160

Physical Properties of Bark

Specific gravity of the outer bark, oven-dry weight, volume at 13 ± 2% moisture content (*6*)	0.60
Specific gravity, oven-dry weight & volume (*7*)	0.62

Chemical Composition of Wood

Proximate Analyses

	Isenberg (*8*)	Carlberg and Kurth (*9*)
Lignin, %	27.4	–
C. & B. cellulose, %	64.5	–
Ash, %	0.43	–
Pentosans		
Total, %	8.86	–
In cellulose, %	7.31	–
Acetic acid, %	1.64	–
Methoxyl, %	4.57	–
Solubility in		
Alcohol-benzene, %	1.43	–
Ether, %	0.23	–
Ethyl ether, %	–	0.24
Ethyl alcohol, %	–	1.83
Hot water, %	1.89	1.28
Cold water, %	1.12	–

Carbohydrates

	Smith and Zavarin (*10*) Sapwood
Free carbohydrates, dry weight basis	
Glucose, %	0.3
Fructose, %	0.2
Sucrose, %	0.3

Other Information Additional data on extractives can be found in Zavarin and Snajberk (*11*), and Erdtman (*12*). Analyses for several parts of the stem are reported by Isenberg (*8*).

Chemical Composition of Bark

Carbohydrates

	Smith & Zavarin (9)	
	Outer bark	Inner bark
Free carbohydrates, dry weight basis		
Glucose, %	tr.	0.08
Fructose, %	–	0.2
Sucrose, %	–	0.1
Arabinose, %	tr.	–
Raffinose, %	–	0.03
Stachyose, %	–	tr.

Other Information. For the chemical composition of bark waxes and cork, see Kurth (*13*).

Pulping

The pulp is used mostly for various grades of printing and wrapping papers.

Kraft. The wood is readily reduced, yield is normal or slightly high, and it is fairly readily bleached.

Mechanical. The wood is readily reduced, is of excellent color and standard strength, and yield is 94%; it requires 15-20% more power than white spruce; has high brightness.

Nitric oxide-oxygen-sodium hydroxide. Pulps made by this two-stage process have strength comparable to that of kraft pulp.

Sulfite. The wood is readily reduced, yield is normal, and it is pulped more readily than California red fir; strength is only slightly lower than western hemlock; it is easily bleached.

Other Information. See Thickens and McNaughton (*14*), Hatch and Holzer (*15*), Wells and Rue (*16*), and Lin (*17*).

Utilization of Wood and Bark

Use Properties of wood. The wood is medium to somewhat coarse in texture, has no characteristic taste or odor when dried, and has no normal resin canals. It is generally straight grained, relatively easy to work, and stays in place when properly dried. The wood is moderately low in beam strength, ability to resist shock, and in nail withdrawal resistance. It is moderately stiff and moderately strong in post strength. It is below the white pines, cedars, redwood, and cypress in paint-holding properties and above Douglas-fir and southern yellow pine. It is among the woods that are easily glued under a wide range of conditions. The heartwood is not resistant to decay, and the sapwood lacks durability. The wood is difficult to penetrate with a preservative.

Calorific Value of Wood

4440 k cal/kg

Chemical uses of wood. Alcohol production: 50 gallons of 95% alcohol per ton by the Madison process.

Other uses of wood. This and other firs are primarily used for lumber and plywood. Other uses are for fresh fruit and vegetable containers.

Other uses of bark. Bark and bark extract are used to make 3-layer particle boards.

Literature Cited

1. Furniss, R. L.; Carolin, V. M. USDA, Forest Serv. Misc. Publ. No. 1339, 1977, 654 p.

2. Anderson, E. A. J. Forestry 49:38-42(1951).

3. Zobel, D. B. Can. J. Bot. 52(6):1435-7(1974).

4. Chang, Y.-P. USDA, Tech. Bull. No. 1095, 1954, 86 p.

5. USDA, Forest Service, Forest Products Laboratory. Agriculture Handbook No. 72, revised August 1974.

6. Cassens, D. L. Forest Prod. J. 24(4):40-5(1974).

7. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.

8. Isenberg, I. H. J. Am. Chem. Soc. 58:2231(1939).

9. Carlberg, G. L.; Kurth, E. F. Tappi 43(12):982-8(Dec. 1960).

10. Smith, L. V.; Zavarin, E. Tappi 43(3):218-21 (March 1960).

11. Zavarin, E.; Snajberk, K. Phytochem. 4(1):141-8(Feb. 1965).

12. Erdtman, H.; Svensk Papperstidn. 47:155(1944).

13. Kurth, E. F. Tappi 50(6):235-8(June 1967).

14. Thickens, J. H.; McNaughton, G. C. USDA, Bull. No. 343. 1916.

15. Hatch, R. S.; Holzer, W. F. TAPPI Monograph No. 4:153(1947).

16. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485. May, 1927. 101 p.

17. Linn, S.-Y. Univ. Calif., Ph.D. Thesis, 1975, 352 p.

PACIFIC SILVER FIR

Scientific Name *Abies amabilis* (Dougl.) Forbes.

Synonyms Lovely fir, silver fir, amabilis fir, red fir, Cascades fir

Family Name Pinaceae

Range West Coast, Alaska (55° N latitude) to Oregon (43° N latitude). At sea level in Alaska and British Columbia but at elevations of 1000-5000 ft (305-1525 m) in Washington and Oregon. The true fir-mountain hemlock type covers about 4 million acres (1.6 million ha).

Silvics The tree has a long, clear, columnar bole, a pyramidal or spirelike crown, and a deep, spreading root system. The most productive sites are well drained, deep soils having abundant but not excessive moisture. Silver fir seldom grows in pure stands, except as small groups. In mixed stands it is commonly associated with Sitka spruce, Douglas-fir, grand fir, western hemlock, and western red-cedar. At higher elevations noble and subalpine firs, Alaska-cedar, western larch, western white pine, Engelmann spruce, and mountain hemlock occur with it. This species is rated as tolerant.

Tree Dimensions 140-160 ft (43-49 m) tall and 2-4 ft (61-122 cm) in diameter in the Olympic Mountains but smaller elsewhere.

Pathology Resistance to decay: low.

Major trunk rots of Pacific silver fir are brown stringy rot (*Echinodontium tinctorium*), and red heart rot (*Stereum sanguinolentum*). Root and butt rots include *Poria subacida* and *Polyporus abietinus*.

The most destructive insect attacking Pacific silver fir is the balsam woolly aphid (*Adelges piceae*), a European species, which can kill a tree in a few years. The fir root bark beetle (*Pseudohylesinus granulatus*), combined with the silver fir beetle (*Pseudohylesinus sericeus*) can be highly destructive, particularly on injured and severely suppressed trees. The flatheaded fir borer (*Melanophila drummondi*) also attacks Pacific silver fir.

Gross Features of the Wood See the description for white fir.

Microscopic Structure of the Wood See the description for white fir. Weight factor (unbleached kraft) 0.95.

Gross Features of the Bark Ashy gray with large, irregular, chalky-colored blotches and resin blisters on trees less than 3 ft (91 cm) in diameter; superficially scaly on the largest trunks; volume, about 16%.

Microscopic Structure of the Bark See the description for white fir.

Physical Properties of Wood

Specific gravity	Green volume	0.35
	Air-dry volume	0.39
	Oven-dry volume	0.42
Density, lb/cu ft (kg/cu m)	Green	36 (577)
	Air-dry	27 (432)
	Oven-dry	26 (416)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	22 (352)

Percent shrinkage, dried to 0% moisture content: r – 4.6, t – 9.8, v – 13.8

Percent moisture content, when green	
Green basis	40
Oven-dry basis	66

Percent moisture content oven-dry basis (*1*)	
Heartwood	55
Sapwood	164

Physical Properties of Bark

Specific gravity (*7*)	Inner bark	0.52
	Outer bark	0.58
Specific gravity oven-dry weight & volume (*8*)		0.68
Moisture content, % oven-dry (*7*)	Inner bark	77
	Outer bark	40

Additional information in this area includes Kennedy and Swan (*2,3*), Mitchell (*4*), and USDA, Forest Service (*5,6*).

A general bibliography on Pacific, silver fir was complied by Williams and Franklin (*9*).

Chemical Composition of Wood

Proximate Analyses

	F.P.L.	Bray, Martin and Schwartz (*10*)	Carlberg and Kurth (*11*)
Lignin, %	29.8	26.6	
C. & B. cellulose, %	59.6	62.1	
Alpha cellulose, %	43.5	44.2	
Pentosans, %	9.0	10.5	
Solubility in			
Alcohol-benzene, %	3.1	2.0	—
Ether, %	1.4	0.3	—
1% NaOH, %	13.7	9.1	—
Hot water, %	4.4	2.0	2.22
Ethyl ether, %	—	—	0.22
Ethyl alcohol, %	—	—	1.40

Rapson *et al.* (*12*) found the ash content to be 0.47%.

Other Information. Information on extractives can be found in Swan (*13*) and Zavarin and Snajberk (*14*). For information on resin acids and fatty acids see Swan (*15*).

Pulping

Kraft. The wood is fairly readily reduced; yield normal or slightly high, and the pulp is strong; it is used for high-grade wrapping papers and fiberboard (*10,16,17,18*).

Mechanical. The wood is fairly readily reduced, and the pulp is of excellent color and standard strength; it requires about the same power as white spruce (*18,19*). Groundwood can be bleached with H_2O_2; a two-stage process is H_2O_2 followed by ZnS_2O_4.

Sulfite. The wood is fairly readily reduced, yield is normal, pulp is of excellent color and good strength, it has high bulk, and it is fairly easily bleached; it is used for newsprint, wrapping papers, book papers, and high-grade printing papers (*18*).

Utilization of Wood and Bark

Use properties of wood. The wood is medium to somewhat coarse in texture and has no normal resin canals. It is generally straight grained, relatively easy to work, and stays in place when properly dried. The wood is moderately low in beam strength and in nail withdrawal resistance. It is moderately stiff and moderately strong in post strength. The firs are below the white pines, cedars, redwood, and cypress in paint-holding properties and above Douglas-fir and southern yellow pine. They are among the woods that are easily glued under a wide range of conditions. The heartwood is not resistant to decay. The wood is difficult to penetrate with a preservative. The sapwood lacks durability.

Calorific value of wood. 16.5 million Btu/air-dry cord; 4.2 million kcal/air-dry cord.

Other uses of wood. The firs are primarily used for lumber and plywood. Most of the lumber is used for construction. The wood is especially suitable for fresh fruit and vegetable containers.

Literature Cited

1. USDA, Forest Service, Forest Products Laboratory. Agriculture Handbook No. 72, revised August 1974.

2. Kennedy, R. W.; Swann, G. W. Inform Rep. For. Prod. Lab., Vancouver, No. VP-X-50, 1969.

3. Kennedy, R. W.; Swann, G. W. Inform. Rep. For. Prod. Lab., Vancouver No. VP-X-33, 1968.

4. Mitchell, H. L. Proc., Soc. Am. Foresters, Denver, Colorado, 1964, p. 169-79.

5. USDA, Forest Serv. U.S. Forest Serv. Res. Pap. FPL-27, 1965.

6. USDA, Forest Serv. Res. Pap. FPL-27, 1965.

7. Smith, J. H. G.; Kozak, A. Forest Prod. Jour. 21(2):38-40 (1971).

8. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.

9. Williams, C. B., Jr.; Franklin, J. F. U.S. Forest Serv. Res. Paper PNW-21, 1965.

10. Bray, M. W.; Martin, J. S.; Schwartz, S. Paper Trade J. 109(18):29(1939).

11. Carlberg, G. L.; Kurth, E. F. Tappi 43(12):982-8(Dec. 1960).

12. Rapson, W. H.; Wayman, M.; Anderson, C. B. Pulp Paper Mag. Can. 66(5):T255-71(May 1965).

13. Swan, E. P. Can. J. Chem. 45(13):1588-90(July 1, 1967).

14. Zavarin, E.; Snajberk, K. Phytochem. 4(1):141-8(Feb. 1965).

15. Swan, E. P. Can. Dept. Forestry, Inform. Rept. VP-X-115: 24 p. (Aug. 1973).

16. Bray, M. W.; Martin, J. S. Tech. Assoc. Papers 30:388(1947); Paper Trade J. 125(16):40(Oct. 16, 1947).

17. Hepher, U. S.; Jahn, E. C. Paper Trade J. 95(19):33(Nov. 10, 1932).

18. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. 1485, May, 1947, 101 p.

19. Thickens, J. H.; McNaughton, G. C. USDA, Bull. 343. 1916.

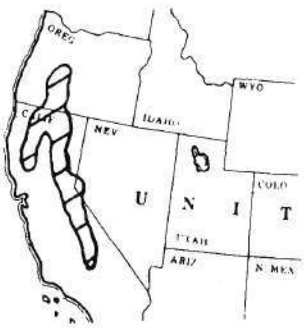
CALIFORNIA RED FIR

Scientific Name *Abies magnifica* A. Murr.

Synonyms Red fir, silvertip, golden fir, white fir, Shasta fir, Shasta red fir

Family Name Pinaceae

Range Southern Oregon and California; latitude 43°35′ N to 35°40′N; 5000-10,000 ft (1520-3050 m) above sea level.



Silvics The tree has a straight, clear, slightly tapering bole and a short, narrow, round-topped crown. Best development is on cool, moist, gravelly or sandy soils in sheltered ravines or on protected slopes but commercial size is reached on much poorer sites. Red fir occurs pure and in mixture in forests above the transition zone. In the north it is associated with Douglas-fir, sugar and ponderosa pines at lower elevations, and with mountain hemlock and lodgepole pine at higher levels. In the Sierra Nevada its neighbors are white fir, lodgepole, western white, ponderosa, Jeffrey, and sugar pines, incense-cedar, giant sequoia, and mountain hemlock. Good seed crops appear at 2 to 3-year intervals but germination is low. This species is rated as intermediate to tolerant. No distinction will be made in this description between California red fir and Shasta fir (var. *shastensis*).

Tree Dimensions 150-180 ft (46-55 m) tall and 4-5 ft (122-152 cm) in diameter.

Pathology Resistance to decay: low.

Major heart rots of California red fir include yellow cap fungus (*Pholiota adiposa*) fomes butt rot (*Heterobasidion annosum*), shoestring fungus (*Armillariella mellea*), sulfur fungus (*Polyporus sulphureus*), and Indian paint fungus (*Echinodontium tinctorium*) (*1*). The dwarf mistletoe species that attacks California red fir is *Arceuthobium campylopodum*.

The fir engraver (*Scolytus ventralis*) causes severe damage to California red fir, attacking trees from pole-size to maturity. Other insect pests of this species are the flatheaded fir borer (*Melanophila drummondi*) and the roundheaded fir borer (*Tetropium abietis*).

Gross Features of the Wood Resembles the wood of noble fir in having a more reddish tinge than the other species of western true firs. See the description for white fir.

Microscopic Structure of the Wood See the description for white fir.

Gross Features of the Bark Smooth and chalky on young stems; 4-6 inches (10-15 cm) thick on old trunks and divided by deep furrows into rounded or plated reddish-brown ridges.

Microscopic Structure of the Bark See the description for white fir.

Physical Properties of Wood

Specific gravity	Green volume	0.37
	Air-dry volume	0.39
	Oven-dry volume	0.42
Density, lb/cu ft (kg/cu m)	Green	48 (769)
	Air-dry	27 (432)
	Oven-dry	26 (416)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	23 (368)

Percent moisture content, when green

Green basis	52
Oven-dry basis	108

Percent shrinkage, dried to 0% moisture content: r – 4.0, t – 7.2, v – 12.2

A reference in this area is USDA, Forest Service (*2*).

Physical Properties of Bark

Specific gravity of the outer bark, oven-dry weight, volume at 13 ± 2% moisture content (*3*)	0.50
Specific gravity, oven-dry weight & volume (*4*)	0.50

Chemical Composition of Wood

Carbohydrates

	Smith and Zavarin (*6*) sapwood	Smith and Zavarin (*6*) heartwood
Free carbohydrates, dry weight basis		
Glucose, %	0.2	tr.
Fructose, %	0.2	—
Sucrose, %	0.2	—
Raffinose, %	tr.	—
Arabinose, %	—	tr.

Chemical Composition of Bark

Free carbohydrates, dry weight basis	Smith and Zavarin (*6*) outer bark	Smith and Zavarin (*6*) inner bark
Glucose, %	tr.	0.8
Fructose, %	—	1.0
Sucrose, %	—	3.0
Raffinose, %	—	0.02
Arabinose, %	tr.	tr.

Extractives. Information can be found in Zavarin and Snajberk (*5*).

Pulping

Kraft. The wood is readily reduced, yield is normal, burst strength good, and tear is low. The pulp is difficult to bleach (*7,8*).

Mechanical. The wood is readily reduced, requiring 15-25% more power than white spruce; the pulp, in a yield of 86%, has a slightly reddish cast, and is of standard strength (*8,9*). Stone groundwood had better printability and poorer tear strength than refiner groundwood when mixed with 40% Canadian kraft (*10*).

Sulfite. The wood is fairly readily reduced, yield is normal, and the pulp is strong, darker than spruce, and fairly easily bleached; it is used for newsprint, wrapping papers, book papers, and high-grade printing papers (*8*).

Utilization of Wood and Bark

Use properties of wood. The wood is medium to somewhat coarse in texture and has no normal resin canals. It is generally straight grained, relatively easy to work, and stays in place when properly dried. The wood is moderately low in beam strength and in nail withdrawal resistance. It is moderately stiff and moderately strong in post strength. The firs are below the white pines, cedars, redwood, and cypress in paint-holding properties and above Douglas-fir and southern yellow pine. They are among the woods that are easily glued under a wide range of conditions. The heartwood is not resistant to decay. The wood is difficult to penetrate with a preservative. The sapwood lacks durability.

Other uses of wood. The firs are primarily used for lumber and plywood. Most of the lumber is used for construction. The wood is especially suitable for fresh fruit and vegetable containers.

Literature Cited

1. USDA, Forest Serv. Agriculture Handbook No. 271, 1965.
2. USDA, Forest Serv. Research Paper FPL 27, 1965.
3. Cassens, D. L. Forest Prod. Jour. 24(4):40-45(1974).
4. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.
5. Zavarin, E.; Snajberk, K. Phytochem. 4(1):141-8(Feb. 1965).
6. Smith, L. V.; Zavarin, E. Tappi 43(3):218-21 (March 1960).
7. Hatch, R. S.; Holzer, W. F. TAPPI Monograph No. 4:153(1947).
8. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485. May, 1927. 101 p.
9. Thickens, J. H.; McNaughton, G. C. USDA, Bull. No. 343. 1916.
10. Braun, R. V.; Davis, J. W. Tappi 52(2):282-88 (Feb. 1969).

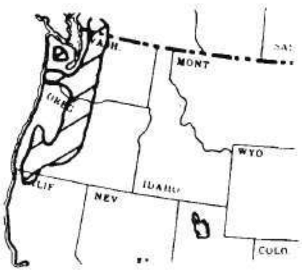
NOBLE FIR

Scientific Name *Abies procera* Rehd.

Synonyms Red fir, white fir

Family Name Pinaceae

Range Pacific Coast from Washington to northern California; 2000-5000 ft (610-1520 m) in elevation. The true fir-mountain hemlock type covers about 4 million acres (1.6 million ha).



Silvics The tree has a long, clear, columnar bole, a domelike crown, and a moderately deep and spreading root system. Best growth is made on a deep, moist, cool site, although good growth is obtained on poorer soils if abundant moisture is present. Noble fir occurs most commonly in mixture with Douglas-fir, western and mountain hemlocks, silver fir, western white and lodgepole pines, and western red-cedar. It is essentially a tree of the mountains. Good seed crops are borne infrequently, although some seed is produced every year. Germination is low. This fir is classed as intolerant.

Tree Dimensions One of the largest true firs; 90-120 ft (27-37 m) tall and 20-24 inches (51-61 cm) in diameter, but apparently will attain much greater size at maturity of 350 years.

Pathology Resistance to decay: low.

Noble fir is relatively free of important diseases, compared to many other firs (*1*). Trunk rot fungi that attack it include Indian paint fungus (*Echinodontium tinctorium*), brown trunk rot (*Fomes laricis*), red ring rot (*Phellinus pini*), and red belt fungus (*F. pinicola*). It is also attacked by the red brown butt rot fungus (*Phaeolus schweinitzii*). The dwarf mistletoe that attacks noble fir is *Arceuthobium campylopodum* forma *abietum*.

The species is also relatively free of insect enemies (*1*). The noble fir bark beetle (*Pseudohylesinus nobilis*) is the only insect that commonly kills the tree. Other insect pests include the flatheaded fir borer (*Melanophila drummondi*), two roundheaded borers (*Tetropium* sp. and *Poliaenus oregonus*) and a twig beetle (*Pityophthorus pseudotsugae*). Although noble fir may become infested with the balsam woolly aphid (*Adelges piceae*), it is never seriously damaged.

Gross Features of the Wood See the description for white fir, except that the wood has a more reddish tinge.

Microscopic Structure of the Wood See the description for white fir. Weight factor (unbleached kraft) 1.24.

Gross Features of the Bark Gray, smooth, with prominent resin blisters when young; eventually dark gray, often tinged with purple and broken into thin, nearly rectangular plates separated by deep fissures on old trunks; l-2 inches thick.

Microscopic Structure of the Bark See the description for white fir.

Physical Properties of Wood

Specific gravity	Green volume	0.35
	Air-dry volume	0.38
	Oven-dry volume	0.40
Density, lb/cu ft (kg/cu m)	Green	30 (481)
	Air-dry	26 (416)
	Oven-dry	25 (400)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	22 (352)

Percent shrinkage, dried to 0% moisture content: r – 4.2, t – 8.3, v – 12.4

Percent moisture content, when green

Green basis	26
Oven-dry basis	36

Physical Properties of Bark

Specific gravity, oven-dry weight & volume (*3*)	0.56

A reference in this area is USDA, Forest Service (*2*).

Chemical Composition of Wood

Proximate Analyses

	Martin (*4*)	Carlberg and Kurth (*5*) % oven-dry wt.
Lignin, %	29.3	
Holocellulose, %	61.3	
Alpha-cellulose, %	42.8	
Pentosans		
Total, %	9.0	
In cellulose, %	9.2	
Solubility in		
Alcohol-benzene, %	2.7	
Ether, %	0.6	0.21
1% NaOH, %	9.6	
Hot water, %	2.3	2.28
Ash, %	0.4	
Solubility in		
Ethanol		2.25

Kurth (*6*) has also analyzed the wood.

Extractives

For total terpene hydrocarbons, see Zavarin and Snajberk (*7*). Conidendrin could not be detected (*8*).

Pulping

Kraft. The wood is readily reduced, yield is normal, and pulp is strong with excellent burst strength and fair tear strength. It is readily bleached. It is used for high-grade kraft wrapping papers and fiberboard (*4,9,10*).

Mechanical. The wood is readily reduced, and the yield is 91%. Color is excellent and strength is standard. It requires 20% less power than spruce (*10,11*).

Sulfite. The wood is readily reduced, yield is normal, and color and strength are excellent. It is easily bleached. It is used for newspapers, wrapping papers, book, and high-grade printing papers (*9,10*).

Other Information. The wood is pulped by any process as easily as spruce and, except for red fir, compares favorably in quality. The pulp is manufactured mostly into various grades of printing paper and wrapping paper.

Utilization of Wood and Bark

Use properties of wood. The wood is medium to somewhat coarse in texture, has no characteristic taste or odor when dried, and it has no normal resin canals. It is generally straight grained, relatively easy to work, and stays in place when properly dried. The wood is moderately low in beam strength, ability to resist shock, and in nail withdrawal resistance. It is moderately stiff and moderately strong in post strength. It is below the white pines, cedars, redwood, and cypress in paint-holding properties and above Douglas-fir and southern yellow pine. It is among the woods that glue easily under a wide range of conditions. The heartwood is not resistant to decay, and the sapwood lacks durability. The wood is difficult to penetrate with a preservative.

Other uses of wood. The wood is primarily used for lumber, pulpwood, and plywood. It is light in weight and color, easy to work, and free from odor, pitch and stain. It is especially suitable for fresh fruit and vegetable containers.

Literature Cited

1. USDA, Forest Service Agriculture Handbook No. 271, 1965.
2. USDA, Forest Service Research Paper FPL-27, 1965.
3. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.
4. Martin, J. S. Tappi 32:534(1949).
5. Carlberg, G. L.; Kurth, E. F. Tappi 43(12):982-8(Dec. 1960).
6. Kurth, E. F. Tappi 33:507(1950).
7. Zavarin, E.; Snajberk, K. Phytochem. 4(1):141-8(Feb. 1965).
8. Erdtmann, H. Svensk Papperstidn. 47:155(1944).
9. Hatch, R. S.; Holzer, W. F. TAPPI Monograph No. 4:153 (1947).
10. Wells, S. D.; Rue, J. D. USDA, Dept. Bull 1485. May, 1927. 101 p.
11. Thickens, J. H.; McNaughton, G. C. USDA, Bull. 343. 1916.

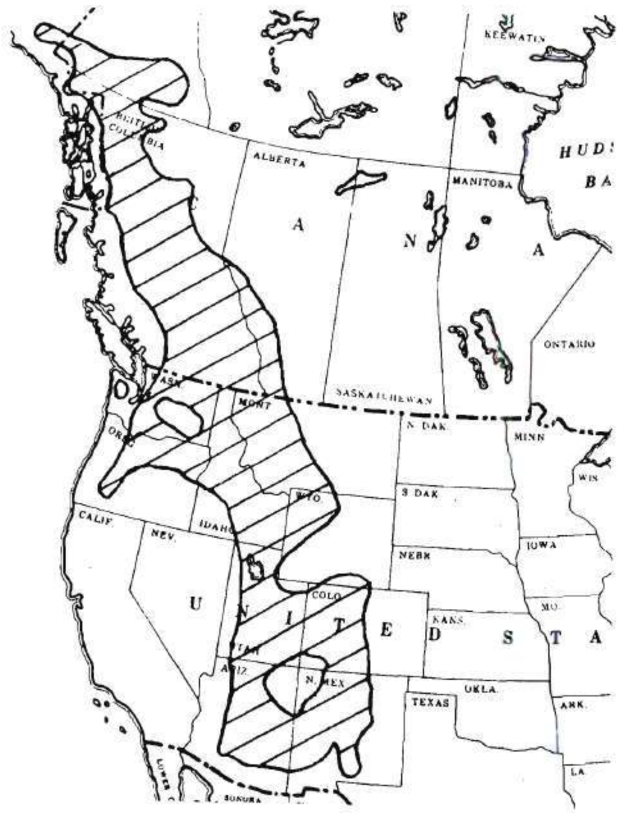
SUBALPINE FIR

Scientific Name *Abies lasiocarpa* (Hook.) Nutt.

Synonyms Alpine fir, balsam, white balsam, balsam fir, white fir

Family Name Pinaceae

Range Western North America. The most widely distributed fir in North America; 2000-8000 ft (610-2440 m) elevation in British Columbia, Washington and Oregon, 3500-9500 ft (1070-2900 m) in the Rockies. The variety, corkbark fir (*Abies lasiocarpa* var. *arizonica*), is found in Colorado, New Mexico and Arizona at elevations of 9500-11,000 ft (2900-3350 m).



Silvics Open-grown trees, particularly at higher elevations, have excessively tapered trunks and dense, spirelike crowns but forest trees have dense, narrowly pyramidal crowns and symmetrical, clear, moderately tapering boles. Root system is shallow and widespreading. Best growth is on moist, porous soils, although dry, sterile sites support moderately-sized trees. This fir forms restricted pure stands but also occurs in mixed forests. The principal associate is Engelmann spruce but it is found with the other alpine species. In northern Idaho it reaches a large size in admixture with grand fir, western white pine, Engelmann spruce, and western larch. In the Pacific region, its chief associates are mountain hemlock, whitebark pine, and Alaska-cedar. Good seed crops are borne about every 3 years, with light crops in between. Subalpine fir is rated as very tolerant.

Tree Dimensions 60-100 ft (18-30 m) tall and 18-24 inches (46-61 cm) in diameter. Often becomes shrublike near the timberline on exposed sites.

Pathology Resistance to decay: low.

Major trunk rots of subalpine fir are brown stringy rot (*Echinodontium tinctorium*), red heart rot (*Stereum sanguinolentum*) and red ring rot (*Phellinus pini*). Root and butt rots include shoestring rot (*Armillariella mellea*) and white spongy root rot (*Poria subacida*). Species of dwarf mistletoe attacking subalpine fir include larch dwarf mistletoe (*Arceuthobium laricis*) and western dwarf mistletoe (*Arceuthobium campylopodum*).

The western spruce budworm (*Choristoneura occidentalis*) is the most destructive forest defoliator in western North America (*1*). Another defoliator of subalpine fir is the backheaded budworm (*Acleris variana*) which kills or severely weakens trees of all ages. The western balsam bark beetle (*Dryocoetes confusus*) kills subalpine fir extensively in the western United States and British Columbia. The balsam woolly aphid (*Adelges piceae*) is another serious pest.

Gross Features of the Wood Similar to white fir but the growth rings are usually narrower. The wood has a mild but distinct rank odor, noticeable when fresh cuts are made. See the description for white fir.

Microscopic Structure of the Wood See the description for white fir except for tracheid dimensions.

Tracheids. Average 3.0 mm in length and 29 μm in diameter. Cell wall thickness averages 2.0 μm.

In a study by Kennedy and Wilson on *Abies lasiocarpa* (*2*), fibers from the wood of smooth-barked trees at breast height are significantly longer than those of cork-bark trees.

Gross Features of the Bark Thin, at most about 1.25 inches, (3.2 cm) thick, hard, flinty, and but little broken on fairly large trees, except occasional shallow, narrow cracks near the base of the trunk. The unbroken smooth parts are ashy gray—often chalky white. Even in old trunks, always irregularly and shallowly seamed, the flat ridges are whitish, but pale brownish on the broken edges and red brown on the inside. However, some forms exist with much thicker corky bark that amounts to as much as 20% of the merchantable volume of the butt log. This cork bark type should not be confused with *Abies lasiocarpa* var. *arizonica* (2).

Microscopic Structure of the Bark See description for white fir. One unique feature of *Abies lasiocarpa* var. *arizonica* is its well-developed cork, which often grows continuously without the formation of rhytidome (*3*). Also characteristic of var. *arizonica* are abundant pocket-like resin passages (*3*). Within the phellem of all periderms in var. *arizonica*, are periodic rows of cells with sclerified outer tangential walls. These rows of cells separate the increments of phellem and are also directly related to the age in young stems (*4*).

Physical Properties of Wood

Specific gravity	Green volume	0.31
	Air-dry volume	0.33
	Oven-dry volume	0.34
Density, lb/cu ft (kg/cu m)	Green	28 (450)
	Air-dry	23 (370)
	Oven-dry	21 (340)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	19 (300)

Kennedy and Wilson studying *Abies lasiocarpa* found that trees with corky bark had significantly higher specific gravity than smooth-barked trees. In both types, minimum specific gravity occurred between the 50th and 70th year (5).

Percent shrinkage, dried to 0% moisture content: r – 2.6, t – 7.4, v – 9.4

Percent moisture content, when green

Green basis	32
Oven-dry basis	47

Physical Properties of Bark

Specific gravity oven-dry weight & volume (*6*)	0.52

Chemical Composition of Wood

Proximate Analysis	Hyttinen, *et al.* (7)
Holocellulose, %	66.5-69.7
Alpha-cellulose, %	44.2-46.9
Lignin, %	27.9-29.6
Total Pentosans, %	8.1-8.9
Solubility in	
Ether, %	0.3-0.9
1% NaOH, %	11.0-12.8
Hot water, %	2.0-3.5
Alcohol-benzene, %	2.1-3.4
Ash, %	0.4-0.5

Extractives. Information on extractives can be found in Drew and Pylant (7), Fraser and Swan (*8*), Swan (*9*), and Zavarin and Snajberk (*10*).

Other Information. For information on fatty acids and resin acids see Swan (*11*).

Pulping

Kraft. The wood is readily reduced, the pulp is strong (*12*), and it can be bleached to 91% brightness.

Mechanical. The wood is readily reduced, yield is 94%, color is excellent, strength is standard, and it requires 15-25% more power than white spruce (*12,13*). Groundwood pulp is suitable for book paper and newsprint (*14*).

Sulfite. The wood is readily reduced, yield is normal, color is excellent, strength is only slightly lower than western hemlock, and it is easily bleached (*12*). The wood makes a good viscose-grade sulfite pulp. The mature wood had a slight resistance to sulfite pulping; except in tear strength it was generally as strong as, or stronger than, western hemlock pulp, and except in burst strength it was comparable to, or better than, black spruce pulp; brightness was well below that of normal spruce pulp (*14*).

Utilization of Wood and Bark

The wood is medium to somewhat coarse in texture and has no normal resin canals. It is generally straight grained, relatively easy to work, and stays in place when properly dried. The wood is moderately low in beam strength and in nail withdrawal resistance. It is moderately stiff and moderately strong in post strength. The firs are below the white pines, cedars, redwood, and cypress in paint-holding properties and above Douglas-fir and southern yellow pine. They are among the woods that are easily glued under a wide range of conditions. The heartwood is not resistant to decay. The wood is difficult to penetrate with a preservative. The sapwood lacks durability.

Other uses of wood. The firs are primarily used for lumber and plywood. Most of the lumber is used for construction. The wood is especially suitable for fresh fruit and vegetable containers.

Literature Cited

1. Furniss, R. L.; Carolin, V. M. USDA, Forest Serv. Misc. Publ. No. 1339, 1977, 654 p.
2. Kennedy, R. W.; Wilson, J. W. Pulp Paper Mag. Can. 55(7):130-32(1954).
3. Chang, Y.-P. USDA, Tech. Bull. No. 1095, 1954, 86 p.
4. Mogensen, H. L. J. Arizona Academy Sci. 5(1):36-40(1968).
5. Kennedy, R. W.; Wilson, J. W. Pulp Paper Mag. Can. 55(9):119-21(1954).
6. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.
7. Drew, J.; Pylant, G. D. Tappi 49(10):430-38(Oct. 1966).
8. Fraser, H. S.; Swan, E. P. Can. Dept. Forestry Bimo. Res. Note 29(2):13(March/April 1973).
9. Swan, E. P. Can. J. Chem. 45(13):1588-90(July 1, 1967).
10. Zavarin, E.; Snajberk, K. Phytochem. 4(1):141-48(Feb. 1965).
11. Swan, E. P. Can. Dept. Forestry, Inform. Rept. VP-X-115: 24 p. (Aug. 1973).
12. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. 1485. May, 1927. 101 p.
13. Thickens, J. H.; McNaughton, G. C. USDA, Bull. 343. 1916.
14. Hyttinen, A.; Keller, E. L.; Schafer, E. R. USDA, Forest Serv., Forest Prod. Lab. Rept. No. 2122 (Sept. 1958). 13 p.

CORKBARK FIR

Scientific Name *Abies lasiocarpa* var. *arizonica* (Merr.) Lemm.

Synonyms Alamo de la sierra

Family Name Pinaceae

Range Scattered mountains in the southern Rockies; 9500-11,000 ft elevation.

Silvics A small tree which grows principally at higher elevations. It is found in association with subalpine fir and also as a replacement for it in mixture with Engelmann spruce.

The characteristics and properties of this variety are similar to those of subalpine fir [*Abies lasiocarpa* (Hook.) Nutt.]. See that species for additional comments on var. *arizonica*.

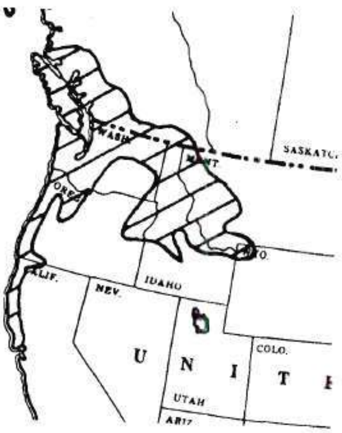
GRAND FIR

Scientific Name *Abies grandis* (Dougl.) Lindl.

Synonyms Lowland white fir, lowland fir, balsam fir, white fir, silver fir, yellow fir

Family Name Pinaceae

Range Northern Rocky Mountains and Pacific Coast regions, including British Columbia; latitude 51° to 39° N and longitude 125° to 114° W.



Silvics The tree has a long, clear, columnar bole, a domelike crown, and a deep, spreading root system. It is found most frequently on deep, moist, alluvial soils in gulches, along streams, and on gentle mountain slopes in mixed hardwood and softwood forests. It occasionally occurs in limited pure stands. Along the coast this species mingles with Sitka spruce, silver fir, western red-cedar, western hemlock, Douglas-fir, redwood, Oregon ash, bigleaf maple, and black cottonwood. Farther east its common associates are Douglas-fir, western larch, western white, ponderosa and lodgepole pines, Engelmann spruce and subalpine fir. Good seed crops are of infrequent occurrence. Grand fir is rated as tolerant to very tolerant.

Tree Dimensions 140-160 ft (43-49 m) tall and 2-4 ft (61-122 cm) in diameter in coastal forests; 115-150 ft (35-46 m) tall and 2-3.5 ft (61-107 cm) in diameter in northern Idaho.

Pathology Resistance to decay: low.

Indian paint fungus (*Echinodontium tinctorium*) is the most serious fungus attacking grand fir east of the Cascade Mountains but is not found on the species west of the Cascades. *Heterobasidion annosum* is the most common cause of rot there. Second in occurrence west of the Cascades are *Stereum* spp. In the area where Indian paint fungus is the most destructive, *Armillariella mellea* and *Phellinus* (*Poria*) *weirii* are the most important root rot fungi.

The most important insects attacking grand fir are defoliators, the spruce budworm (*Choristoneura fumiferana*) and the Douglas-fir tussock moth (*Orgyia pseudotsugata*). The principal bark beetle pests of grand fir are the western balsam bark beetle (*Dryocoetes confusus*) and the fir engraver (*Scolytus ventralis*). The balsam woolly aphid (*Adelges piceae*) also attacks grand fir.

Gross Features of the Wood See the description for white fir.

Microscopic Structure of the Wood See the description for white fir.

Tracheids. Weight factor (unbleached kraft) 0.90.

The effect of aphid infestation on the properties of grand fir is covered by Foulger (*1*). He found that wood formed during infestation had shorter tracheids, greater fibril angle, wider growth rings, greater percentage of latewood, and higher specific gravity than would be expected in the absence of aphid attack.

Gross Features of the Bark Rather thick, smooth, gray brown, with resin blisters and chalky-white blotches on young stems; reddish brown, plated or more commonly deeply furrowed or divided into flat ridges on old trunks. Inner bark 3/16 to 3/8 inch (0.5-1.0 cm) thick, light yellowish brown. Periderm rather broad and often with layered appearance. Zobel (*2*) describes a chimera of red and yellow periderm color from a tree in a population intermediate between *A. concolor* and *A. grandis*.

Microscopic Structure of the Bark (*3*)

Periderm. Composed of well-developed phellem, a layer of phellogen and conspicuous phelloderm. Phellem often remains up to 40 layers in a periderm layer.

Sieve Cells. In radial rows of about 5 cells, interspersed by one or two parenchyma cells; cells aligned rather regularly at region close to cambium; rectangular in cross section, about 15-25 μm in radial dimension and 20-55 μm in tangential dimension; rather short, mostly about 2.5 mm long.

Phloem Fibers. None

Sclereids. Formation begins rather early, appearing about 5 or 10 cells from first-formed phloem tissues. Individual cells mostly much branched and twisted, outline in cross section irregular and more or less oval; walls very thick and uneven in thickness. Cell size variable, mostly about 600 μm long; diameter of main body mostly about 60 μm, but sometimes about 20 μm. Usually about 10-15 cells form a group; often locally aligned more or less in tangential rows, mostly diffused but rather crowded at outer part of inner bark.

Parenchyma. Well developed in region close to cambium; usually 1 or 2 cells appearing at an interval of about every 5 sieve cells; aligned more or less in tangential lines; obliterated and indistinct in cross section because of expanded sclereids but sometimes conspicuously expanded at spaces among sclereid groups. Individual cells about 100 μm high and 30-40 μm in tangential dimension; conspicuously expanded, with cell walls becoming thicker and lignified at outer portion of inner bark; containing single crystals of calcium oxalate.

Rays. Phloem rays at newly developed inner bark similar to corresponding xylem rays; mainly uniseriate or partially biseriate; mostly 10-20 cells but sometimes up to 40 cells or 800 μm high. Marginal erect cells or albuminous cells distinct only in region very close to cambium. No fusiform rays nor distinct resin pocket formed from enlarged marginal ray cell.

Physical Properties of Wood

Specific gravity	Green volume	0.37
	Air-dry volume	0.40
	Oven-dry volume	0.41
Density, lb/cu ft (kg/cu m)	Green	45 (721)
	Air-dry	28 (448)
	Oven-dry	26 (416)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	23 (368)

Percent moisture content, when green

Green basis	48
Oven-dry basis	94

Percent moisture content, oven-dry basis (*4*)

Heartwood	91
Sapwood	136

Percent shrinkage, dried to 0% moisture content: r – 3.4, t – 7.5, v – 11.0

References in this area include USDA, Forest Service (*5*) and Stage (*6*).

Physical Properties of Bark

Specific gravity green volume (*7*)	Inner bark	0.63
	Outer bark	0.70
Specific gravity oven-dry weight & volume (*8*)		0.61
Percent moisture content, oven-dry basis (*7*)	Inner bark	81
	Outer bark	51

Chemical Composition of Wood

Proximate Analyses

	F.P.L.	Hepher and Jahn (*9*)	Carlberg and Kurth (*10*)
Lignin, %	27.2	29.5	–
C. & B. cellulose, %	62.8	56.0	–
Alpha-cellulose, %	45.9	–	–
Ash, %	–	–	–
Pentosans, %	8.9	10.9	–
Solubility in			
Alcohol-benzene, %	2.6	3.26	–
Ether, %	0.9	1.93	–
1% NaOH, %	10.3	–	–
Hot water, %	2.3	1.96	1.20
Cold water, %	–	1.26	–
Ethyl ether, %	–	–	0.19
Ethyl alcohol, %	–	–	1.43

Carbohydrates

	Smith and Zavarin (*12*)	
	sapwood	heartwood
Free carbohydrates, dry weight basis		
Glucose, %	0.09	tr.
Fructose, %	0.09	—
Sucrose, %	0.2	—
Arabinose, %	—	tr.

Chemical Composition of Bark

Carbohydrates

	Smith and Zavarin (*11*)	
	Outer bark	Inner bark
Free carbohydrates, dry weight basis		
Glucose, %	0.02	0.07
Fructose, %	—	0.04
Sucrose, %	—	tr.
Arabinose, %	0.01	—

Extractives. See Swan (*13*), Kasper (*14*), and Zavarin and Snajberk (*15*).

Other Information. For inorganic constituents, see Ellis (*16*).

Corder (*11*) found the ash content to be 2.5%.

Pulping

Kraft. The wood is readily reduced, yield is normal, the pulp has good strength with balance between burst and tear maintained, and it is fairly readily bleached (*18,19*). Kraft pulping without bark gives yield of 46% (kappa no. 30.7); with bark, the yield is 44% (kappa no. 31.5). (*20*).

Mechanical. The wood is readily reduced, yield is 91%, and the pulp is of excellent color; it requires 15-25% more power than white spruce (*19,21*).

Sulfite. The wood is readily reduced, yield is normal, pulp strength is slightly lower than western hemlock, good balance between burst and tear is maintained, color is excellent, and the pulp is readily bleached (*18,19,21*).

Sulfite, Ammonia-base. See La Fond and Holzer (*23*).

Other information. The pulp is manufactured mostly into various grades of printing paper and wrapping paper.

Utilization of Wood and Bark

Use properties of wood. The wood is medium to somewhat coarse in texture and has no normal resin canals. It is generally straight grained, relatively easy to work, and stays in place when properly dried. The wood is moderately low in beam strength and in nail withdrawal resistance. It is moderately stiff and moderately strong in post strength. The firs are below the white pines, cedars, redwood, and cypress in paint-holding properties and above Douglas-fir and southern yellow pine. They are among the woods that are easily glued under a wide range of conditions. The heartwood is not resistant to decay. The wood is difficult to penetrate with a preservative. The sapwood lacks durability.

Calorific value of wood.

17.4×10^6 BTU/air-dry cord
4.4×10^6 kcal/air-dry cord

Other uses of wood. The firs are primarily used for lumber and plywood. Most of the lumber is used for construction. The wood is especially suitable for fresh fruit and vegetable containers.

Other uses of bark. Bark extract is used as a bonding agent for particle board.

Literature Cited

1. Foulger, A. N. Forest Prod. Jour. 18(1):43-7(1968).
2. Zobel, D. B. Can. J. Bot. 52(6):1435-7(1974).
3. Chang, Y.-P. USDA, Tech. Bull. No. 1095, Dec. 1954.
4. USDA, Forest Service, Forest Products Laboratory. Agriculture Handbook No. 72, revised August 1974.
5. USDA, Forest Serv. Res. Pap. FPL-27, 1965.
6. Stage, A. R. USDA, Forest Serv. Res. Pap. INT-4, 1963.
7. Smith, J. H. G.; Kozak, A. Forest Prod. J. 21(2):38-40(1971).
8. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.

9. Hepher, U. S.; Jahn, E. C. Paper Trade J. 95(19):33(Nov. 10, 1932).

10. Carlberg, G. L.; Kurth, E. F. Tappi 43(12):982-8(Dec. 1960).

11. Corder, S. E. Properties and uses of bark as an energy source. XVI IUFRO World Congress, Oslo, Norway, June 20-July 2, 1976, Research Paper 31.

12. Smith, L. V.; Zavarin, E. Tappi 43(3):218-21 (March 1960).

13. Swan, E. P. Can. J. Chem. 45(13):1588-90(July 1, 1967).

14. Kasper, J. B. Can. J. Bot. 47(4):551-3(April 1969).

15. Zavarin, E.; Snajberk, K. Phytochem. 4(1):141-8(Feb. 1965).

16. Ellis, E. L. Forest Prod. J. 12(6):271-4(1962).

17. Rogers, I. H.; Grierson, D. Wood Fiber 4(1):33-37(Spring 1972).

18. Hatch, R. S.; Holzer, W. F. TAPPI Monograph No. 4:153(1947).

19. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. 1485. May, 1927. 101 p.

20. Horn, R. A.; Auchter, R. J. Paper Trade J. 156(46):55-59(Nov. 6, 1972).

21. Thickens, J. H.; McNaughton, G. C. USDA, Bull. 343. 1916.

22. McGovern, J. N. Paper Trade J. 103(20):29(1936).

23. La Fond, L. A.; Holzer, W. F. Tappi 34:24(1951).

REDWOOD

Scientific Name *Sequoia sempervirens* (D. Don) Endl.

Synonyms Coast redwood, California redwood

Family Name Taxodiaceae

Range Pacific Coast region from southwestern Oregon to central California; sea level to 2500 ft (760 m) elevation. The redwood type was estimated to cover 915,000 acres (370,600 ha) in 1968 (*7*).

Silvics The tree has a very tall, clear, buttressed, and moderately tapering bole, a short, narrow, irregularly conical crown, and a moderately deep and widespreading root system. Redwood is restricted to the California fog belt and is the dominant species in this region. Although the main bodies of redwood are close to the ocean, redwood does not tolerate ocean winds and appears to be sensitive to salt spray sometimes carried inland by storms. Redwoods become smaller and give way to other species as altitude, dryness, and slope increase. Pure stands are found only on some of the best sites, usually the moist river flats and gentle slopes below 1000 ft (300 m). Although this species is dominant throughout its range, it generally is mixed with other species. Most important of these is Douglas-fir. Other important associates are western hemlock, grand fir, Sitka spruce, tanoak and Pacific madrone. Although redwood is a prolific annual producer of seed, reproduction by seed is poor. Fortunately, numerous and vigorous sprouts originate close to the stumps from adventitious buds on the large lateral roots; these sprouts grow quite rapidly and soon form their own root system. This species is rated as tolerant to very tolerant and seems to endure suppression indefinitely.

Tree Dimensions Very large tree (world's tallest), 200-275 ft (61-84 m) tall and 8-12 ft (244-366 cm) in diameter.

Pathology Resistance to decay: very durable.

The worst enemy of young redwood trees, with their thin bark, is fire. Redwood has no killing diseases but heart rots cause extensive cull (*2*). The most serious of these is the brown cubical rot (*Poria sequoiae*) which causes about 7.5 billion board ft (26.6 million cu m) of cull in redwood (*3*). White ring rot (*P. albipellucida*) is the only other rot of any consequence. This rot increases in severity from the southern part of the range to the northern part.

Although some insects are found on redwood, none of them cause significant damage. Included are the redwood bark beetle (*Phloesinus sequoiae*) and a flatheaded borer (*Anthaxia aeneogaster*), the larvae of which bore into branches of injured, dying and dead trees.

Gross Features of the Wood The wood of redwood is soft to moderately hard, generally straight grained, coarse textured, and without characteristic odor or taste. The sapwood is almost white and very narrow in old trees. The heartwood is clear light red to deep reddish brown. The grain is even in old slow growth or uneven in second growth. The earlywood zone is usually much wider than the latewood zone. The transition from earlywood to latewood is generally abrupt. The darker latewood is very narrow in old growth to very wide in sprout second growth. The growth rings are distinct. In the x-section the rays are coarse for a coniferous wood, generally visible without magnification because of their lighter color as compared with the background, and form a fine, close, relatively conspicuous fleck on the radial surface. Normal resin canals are absent, but traumatic (wound) canals are sometimes present; if so, they are sporadic and arranged in a tangential row, appearing as dark streaks along the grain. Longitudinal parenchyma cells are abundant, scattered, readily visible in the sapwood with a hand lens and sometimes without magnification because of their contents, inconspicuous in the dark-colored heartwood.

Microscopic Structure of the Wood

Tracheids. Average 7.0 mm (2.9-9.3 mm) in length and 50-65 μm in diameter. Cell wall thickness averages are: young growth earlywood 3.77 μm, young growth latewood 5.86 μm, old growth earlywood 4.23 μm, old growth latewood 6.60 μm (*4*). Coarseness of 26.8 mg/100 m. Bordered pits in 1-3 (generally 2) rows on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma fairly large, quite uniform in size, oval for the most part (taxodioid), 1-4 (generally 2-3) per cross-field; ray tracheid pits usually absent. Volume occupied, approximately 91%. Bailey and Faull (*5*), in studying tracheid length in stem, branches and roots of redwood, found the longest tracheids in the roots, the shortest in the branches.

Rays. Uniseriate and rather frequently partly biseriate, consisting entirely of ray parenchyma or rarely with marginal or isolated ray tracheids; up to 40 cells (800 μm) in height. Volume occupied, approximately 8%.

Longitudinal Parenchyma. Apotracheal-diffuse, solitary or occasionally 2 or more contiguous tangentially, conspicuous because of their dark resinous contents. Volume occupied, approximately 1%.

Publications in this area include Jane (*6*), Sastry and Wellwood (*7*) and Tsoumis (*8*).

Gross Features of the Bark Thick-barked tree. The bark is sometimes as much as a foot thick on merchantable trees but is usually much less. In external appearance it is reddish, deeply furrowed, and scaly. In transverse section the bark appears as two strikingly different colored rings – the very thin, whitish, inner one and the thicker, reddish-brown, outer one. The light-colored layer, which may have a pinkish tinge, rarely exceeds one quarter of an inch in thickness (*9*).

Microscopic Structure of the Bark

Periderm. Layers usually overlap each other for a short distance in the tangential direction (*10*). Only a few rows of cork cells are formed by the phellogen, and an approximately equal number of phelloderm cells are formed. The cells constituting the phellem are uniform in shape (*9*).

Phloem Fibers. Thick walls and slitlike lumen. Average 7.1 mm in length in the inner bark and 6.6 mm in length in the outer bark. Relative volume occupied by phloem fibers in the bark is 18.7% in the inner bark and 5.6% in the outer bark (*9*). Phloem fibers develop a short distance from the cambium and the tangential, uniseriate rows are spaced rather evenly throughout the bark (*9*). Fibers close to the cambium are mostly radially flattened and regular in size and shape while square fibers and especially radially elongated ones occur mostly in the outer part of the inner bark and in the rhytidome of the outer bark (*10*).

Parenchyma (9). Rectangular, or more or less rounded in cross section because of bulging tangential walls with the larger dimension tangential. Height of cell several times greater than either transverse dimension. Average length of phloem parenchyma is 180 μm, ranging from 110-300 μm.

Sieve Cells (9). Similar to other gymnosperms, sieve cell elements are not arranged in series, end to end, forming definite conducting lines but are separate and distinct.

Sieve plates are scattered irregularly on the radial walls with diameters only slightly less than of the cell itself.

Rays (9). Mostly uniseriate, although not infrequently biseriate. Consists entirely of parenchyma cells. Vary in height from one to many (approximately 700 μm). Average length of the ray cell is 130 μm, ranging from 80-250 μm. Approximately four rays per millimeter tangentially, as measured in cross section.

Physical Properties of Wood

		Old Growth	Second Growth
Specific gravity	Green volume	0.38	0.33
	Air-dry volume	0.40	0.34
	Oven-dry volume	0.41	
Density, lb/cu ft (kg/cu m)	Green	50 (801)	
	Air-dry	28 (448)	
	Oven-dry	26 (416)	
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	24 (384)	21

In a publication by Resch and Arganbright (*11*), density of old growth correlates highly with percent latewood. Density also increases slightly with height and decreases in the outer growth rings toward the bark as the rings narrowed.

Another publication in this area is Bendtsen (*12*).

Percent shrinkage, dried to 0% moisture content:
Old growth, r – 2.6, t – 4.4, v – 6.8
Second growth, r – 2.2, t – 4.9, v – 7.1

Percent moisture content, when green

Green basis	53
Oven-dry basis	112

Percent moisture content, oven-dry basis, old-growth wood (*13*)

Heartwood	86
Sapwood	210

Physical Properties of Bark

Specific gravity, oven-dry weight & volume (*14*)	0.46
Specific gravity of the outer bark, oven-dry weight, volume at 21% moisture content, (*15*)	0.43

Chemical Composition of Wood

Proximate Analyses

	F.P.L.	Dore	Lewis (*17,18*)	
	Heartwood	(*16*)	Sapwood	Heartwood
Lignin, %	34.2	34.5	32.2	30.8
C. & B. cellulose, %	48.5	54.9	53.5	45.2
Alpha-cellulose, %	38.2	–	–	–
Ash, %	0.21	–	–	–
Pentosans				
Total, %	9.43	–	12.2	10.2
In cellulose, %	8.85	–	–	–
Acetic acid, %	1.08	–	–	–
Galactan, %	–	0.50	–	–
Mannan, %	–	3.21	–	–
Methoxyl, %	5.21	–	–	–
Solubility in				
Alcohol, %	–	4.39	1.9	13.2
Alcohol-benzene, %	–	–	1.6	12.1
Benzene, %	–	0.34	–	–
Ether, %	1.07	–	–	–
1% NaOH, %	20.0	–	–	–
Hot water, %	9.86	–	2.8	11.3
Cold water, %	7.36	–	–	–

Wise (*79*) attempted the following summative analysis after preparing holocellulose by the sodium chlorite method.

Lignin, %	31.30
Alcohol extract, %	21.83
Water extract (after alcohol), %	1.80
Alpha-cellulose (cor.), %	35.75
Hemicelluloses, %	9.63
Acetyl, %	0.28
Total, %	100.59

A similar study was made for alcohol extractives in various parts of a tree (Lewis, *17*).

Carbohydrates	Smith and Zavarin (*20*) % dry wt.	
	Sapwood	Heartwood
Glucose	0.1	tr.
Fructose	0.1	–
Sucrose	0.03	–
Raffinose	0.03	–
Arabinose	–	0.02

Extractives. The sapwood contained 1.15% tannin, and the heartwood, 12.2% (*21*). Both tannin and phlobaphene have been isolated from the extracts, and their chemical nature has been studied (*22*). The heartwood contains pinite (monomethylhexahydroxycyclohexane) (*23*) and sequoyitol, a monomethyl ether of inactive inositol (*24*). Two coloring matters were found in the heartwood: isosequein and sequoyin. Sequoyin hydrolyzes to sequein and sequeinol. These give color reactions similar to those of tannin and phlobaphene (*25*). For information on sequirins see Hatam and Whiting (*26*), Balogh and Anderson (*27,28*).

Other Information. Typical proximate analysis of moisture-free sawdust (*29*):

Volatile matter	83.5%
Charcoal	16.1%
Ash	0.4%

For information on hemicelluloses see Dutton and Joseleau (*30*).

Chemical Composition of Bark

Carbohydrates

	Smith and Zavarin (*31*) % dry weight	
	Outer bark	Inner bark
Arabinose	0.02	–
Rhamnose	tr.	–
Glucose	0.02	0.2
Fructose	–	1.0
Sucrose	–	0.2

Pulping

Kraft. The wood is readily reduced; yield is low; pulp is relatively low in burst strength and good in tear strength. The pulp is difficult to bleach; best results are obtained when chips are leached before cooking and 10-20% of the weight is extracted (*18,32-34*); for kraft pulp characteristics see Horn and Auchter (*35*).

Sulfite. Although the wood is readily reduced, it is unevenly reduced; the yield is low; the pulp is fairly strong yet brash, shivy, dark in color, and difficult to bleach (*18,33,34*).

Other Pulping Information. The wood can also be pulped by the nitric acid process (*18,33*), Asplund, and Masonite processes (*33*).

Utilization of Wood and Bark

Use properties of wood. The wood is moderately light in weight, moderately strong, stiff, hard, and intermediate in nail-holding ability. The wood is easy to work, not difficult to season, generally straight-grained, and shrinks and swells comparatively little. The heartwood is very resistant to decay. It is among the highest of woods in paint-holding ability. It is only moderately resistant to termites.

Redwood is used for building construction and heavy construction. It is also used for boxes and crates and planing mill products. Because of its durability it is also used for cooling towers, tanks, silos, caskets, boxes for cigars and tobacco, and outdoor furniture.

Calorific Value of Wood

5020 k cal/kg

Chemical uses of wood. Alcohol production: 41-45 gallons (155-170 liters) of 95% alcohol per ton by the Madison process. Various parts of the tree have been subjected to destructive distillation, with interesting results (*17*).

Other uses of bark. Powdered bark is used with carbon black in synthetic rubber latex to prevent shrinkage. It is also used for insulation. Bark dust is used in oil well drilling.

Literature Cited

1. USDA, Forest Service, Agriculture Handbook No. 445, 1973.
2. USDA, Forest Service, Agriculture Handbook No. 271, 1965.
3. USDA, Forest Service, Agriculture Handbook No. 521, 1978.
4. Smith, D. M.; Miller, R. B. Tappi 47(10):599-604(1964).
5. Bailey, I. W.; Faull, A. F. J. Arn. Arb. 15:233-54(1934).
6. Jane, F. W. New Phytol. 55(3):367-8(1956).

7. Sastry, C. B. R.; Wellwood R. W. Tappi 55(6):901-3(1972).

8. Tsoumis, G. IAWA Bull. No. 2:11-16(1974).

9. Isenberg, I. H. Madrono 7(3):85-91(1943).

10. Chang, Y.-P. USDA Tech. Bull. No. 1095, 1954.

11. Resch, H. Forest Sci. 14(2):148-55(1968).

12. Bendtsen, B. A. USDA, Forest Serv. Res. Pap. FPL-53, 1966.

13. USDA, Forest Service. Forest Prod. Lab. Agriculture Handbook No. 72, 1974.

14. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969.

15. Cassens, D. L. Forest Prod. J. 24(4):40-5(1974).

16. Dore, W. H. J. Ind. Eng. Chem. 12:476(1920).

17. Lewis, H. F. The Vortex 7(5)(May, 1946).

18. Lewis, H. F. Tappi 34:385(1951).

19. Wise, L. E. Ind. Eng. Chem. Anal. Ed. 17:63(1945).

20. Smith, L. V.; Zavarin, E. Tappi 43(3):218-21 (March 1960).

21. Scalione, C. C.; Merrill, D. R. J. Ind. Eng. Chem. 11:643(1919).

22. Buchanan, M. A.; Lewis, H. F.; Kurth, E. F. Ind. Eng. Chem. 36:907(1944).

23. Sherrard, E. C.; Kurth, E. F. Ind. Eng. Chem. 20:722(1928).

24. Sherrard, E. C.; Kurth, E. F. J. Am. Chem. Soc. 51:3139(1929).

25. Sherrard, E. C.; Kurth, E. F. Ind. Eng. Chem. 24:300(1933).

26. Hatam, N. A. R.; Whiting, D. A. J. Chem. Soc. 14C:1921-32(1969).

27. Balogh, B.; Anderson, A. B. Phytochem. 4:569-75(1965).

28. Balogh, B.; Anderson, A. B. Phytochem. 4(3):325-30(May, 1966).

29. Mingle, J. G.; Boubel, R. W. Wood. Sci. 1(1):29(July, 1968).

30. Dutton, G. G. S.; Joseleau, J.-P. Cellulose Chem. Technol. 11(3):313-19(May/June 1977).

31. Smith, L. V.; Zavarin, E. Tappi 43(3):218-21 (March 1960).

32. Hatch, R. S.; Holzer, W. F. TAPPI Monograph No. 4:153(1947).

33. The Institute of Paper Chemistry. Research Bull. 12(2):129(Dec. 1945).

34. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485, May, 1927, 101 p.

35. Horn, R. A.; Auchter, R. J. Applied Polymer Symposium No. 28, 529-39(1976).

BALDCYPRESS

Scientific Name *Taxodium distichum* (L.) Rich.

Synonyms Southern-cypress, cypress, swamp-cypress, red-cypress, yellow-cypress, white-cypress, tidewater red-cypress, gulf-cypress

Family Name Taxodiaceae

Range Atlantic and Gulf Coastal plains; Mississippi Valley to southern Illinois. Mostly at elevations less than 100 ft (30 m) above sea level. The oak-gum-cypress forests cover 13 million acres (5.3 million ha) within the southeastern Atlantic Coast Plain (*1*).

Silvics This large-sized tree has a cylindrical trunk with a swollen, fluted base, an irregularly flattened crown, and a shallow, widespreading root system from which rises, especially on wetter sites, peculiar conical outgrowths known as "knees." In young trees the trunk tapers considerably and supports an open, narrow, pyramidal crown. Although its best growth has been found on deep, moist, fine sandy loams with moderately good drainage, it rarely occurs on such sites, possibly because of competition from the more tolerant hardwood species such as sweetgum, green ash, and Nuttall oak. Baldcypress is usually restricted to very wet soils consisting of mucks, clays, or the finer sands where moisture is abundant and fairly permanent. Although best adapted to freshwater swamps, cypress does grow (rather poorly) in brackish tidewater. Often found in extensive pure stands, its chief associates are water tupelo in the alluvial flood plains, or swamp tupelo in the Coastal Plain swamps and estuaries. Other common associates are pondcypress, black willow, swamp cottonwood, red maple, Atlantic white-cedar, green, pumpkin, and Carolina ashes, waterlocust, redbay, persimmon, overcup oak, and water hickory. Some seed is produced every year, with good crops about every three years. Younger trees will sprout from the stump during the dormant period. The species is rated as intermediate in tolerance.

Pathology

By far the most important fungus disease of baldcypress is a brown pocket rot caused by *Stereum* (*Echinodontium*) *taxodii*. Working down from rotted branch stubs in old trees, this fungus produces a pitted effect in the wood, known as "pecky cypress." This decay process stops once the tree is cut. Other diseases of baldcypress are not of economic importance.

Although several insects attack baldcypress, none cause mortality. However, serious degrade of lumber is caused by a number of wood-boring insects. The cypress bark borer (*Physocnemum andreae*) and the flatheaded baldcypress sapwood borer (*Acmaeodera pulchella*) damage the sapwood while the flatheaded baldcypress heartwood borer (*Trachykele lecontei*) and the ambrosia beetle (*Platypus compositus*) damage the heartwood (*2*).

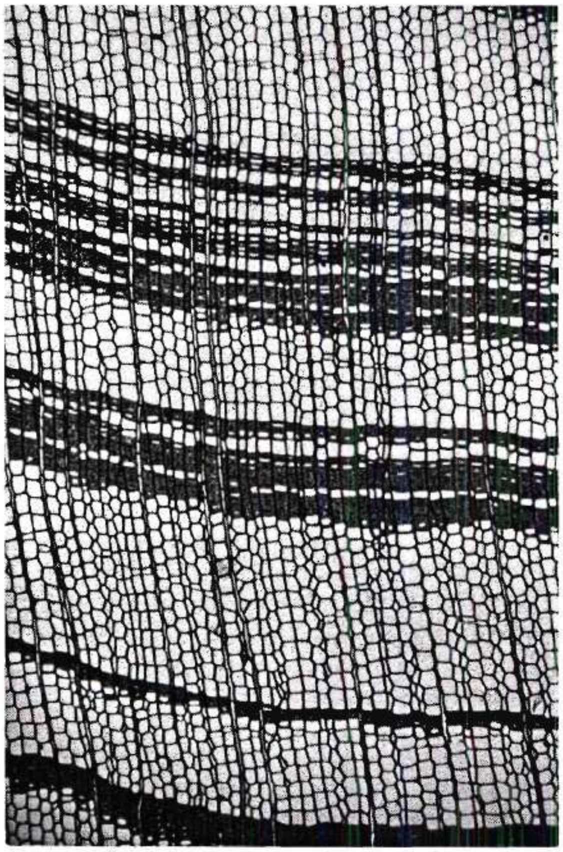
Gross Features of the Wood The wood of baldcypress is moderately hard, moderately heavy, generally straight- and even- or uneven-grained, coarse-textured, with a greasy feel, and often with a rancid odor, although no taste, odor, or color is imparted to materials in contact with it. The sapwood is pale yellowish-white and merges more or less gradually into the heartwood, which is very variable in color, ranging from yellowish to light or dark brown, reddish brown, or almost black. (The color tends to be lighter in the northern part of the range.) The earlywood zone is narrow to wide, usually several times wider than the latewood zone. The transition from earlywood to latewood is generally abrupt. The latewood zone can be conspicuous or inconspicuous and narrow or broad in wide growth rings. The growth rings are distinct. In the x-section the rays are rather coarse and form a fine, relatively conspicuous fleck on the radial surface. Normal resin canals are absent. Longitudinal parenchyma cells are abundant, scattered, readily visible in the lighter-colored samples with a hand lens and sometimes without magnification because of their dark-colored contents. Brown, friable masses of decayed wood, known as brown rot or peckiness, are often present.

Microscopic Structure of the Wood

Tracheids. Average 6.2 mm (2.9-9.7 mm) in length and 45-60 μm in diameter; bordered pits in 1-4 (frequently 3) rows on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma fairly large, quite uniform in size, orbicular for the most part (taxodioid or more rarely cupressoid), 1-6 (generally 4) per cross-field; ray tracheid pits absent. Volume occupied, approximately 93%.

Rays. Uniseriate or rarely in part biseriate, consisting entirely of ray parenchyma; up to 60 cells in height. Volume occupied, approximately 6%.

Longitudinal Parenchyma. Apotracheal-diffuse, solitary or occasionally 2 or more contiguous tangentially, conspicuous because of their dark resinous contents. Volume occupied, approximately 1%.



Cross section of baldcypress, a coarse-textured wood. Growth rate and age are difficult to determine due to false growth rings. Magnification 20X.

Additional information in this area includes Timell (*3*) and Thomas (*4*).

Gross Features of the Bark Variable; fibrous and up to 1.5 inch (3.8 cm) thick, or scaly and thin, reddish brown, but often weathering to ashy-gray on the surface. Inner bark narrow, about 1/16 to 1/8-inch (0.16-0.32 cm) thick; light yellowish brown after exposure to air; fine tangential fiber lines and rays visible under lens (*5*).

Microscopic Structure of the Bark (*5*)

Periderm. Thin, usually composed of 2-5 layers of phellem cells, a layer of phellogen, and about 2 layers of phelloderm. Phellem cells thin walled and uniform in thickness; rectangular in cross section, about 15 μm in radial dimension and 30 μm in tangential dimension; vertically about 50-80 μm high on radial section. Phelloderm cells usually wider and with thicker walls than phellem cells; sometime mingled with parenchyma cells of the secondary phloem. Both phellem and phelloderm cells often contain a resinous substance. Rhytidome layers are rather narrow because only about 18 cells of the secondary phloem tissue are included.

Sieve Cells. Differentiated regularly in alternate layers with phloem parenchyma and fibers; about 15-20 μm and 50 μm in radial and tangential dimensions, respectively, in cross section; mostly about 4 mm long but variable from 2-5.5 mm.

Phloem Fibers. Differentiated regularly, usually flattened radially and about the same size and shape throughout most of the inner bark; occasionally some fibers not much lignified or some tending to be square in cross section; about the same length as adjacent sieve cells but fibers at outer bark comparatively shorter than those in the inner bark.

Parenchyma. Parenchyma strands about the same length as sieve cells and fibers. Individual cells mostly 50-100 μm high, occasionally up to 180 μm; about 30-50 μm in tangential dimension and usually about 35 μm in diameter radially; contain starch and sometimes an abundant resinous substance.

Rays. Mainly uniseriate, occasionally partially biseriate; mostly 10-15 cells or 200-300 μm, sometimes up to 30 cells or 500 μm high; not much dilated at outer part of inner bark. Individual cells rather small, about 50-80 μm in radial dimension and 20 μm high on radial section.

Additional information in this area can be found in Evert, *et al.* (*6*).

Physical Properties of Wood

Specific gravity	Green volume	0.42
	Air-dry volume	0.46
	Oven-dry volume	0.47
Density, lb/cu ft (kg/cu m)	Air-dry	33 (529)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	26 (416)

Percent shrinkage, dried to 0% moisture content: r – 3.8, t – 6.2, v – 10.5.

Percent moisture content, when green

Green basis	48
Oven-dry basis	91

Percent moisture content, oven-dry basis (7)	
Heartwood	121
Sapwood	171

Chemical Composition of Wood

Proximate Analyses

	Ritter & Fleck (9)			
	Sap I	Heart I	Sap II	Heart II
Ash, %	0.48	0.30	0.86	0.95
Solubility in				
Cold water, %	0.72	2.79	1.76	3.27
Hot water, %	1.42	2.99	2.30	3.49
Ether, %	0.23	4.87	2.80	7.93
1% NaOH, %	8.55	10.59	10.63	13.56
Acetic acid, %	0.77	0.48	0.65	0.29
Methoxyl, %	4.35	3.94	4.99	4.07
Pentosan, %	8.03	6.67	9.23	7.88
Me Pentosan, %	4.38	4.49	3.34	3.36
C. & B. cellulose, %	54.86	53.10	50.94	49.18
Lignin, %	35.01	33.06	35.31	32.27
In cellulose,				
Pentosan, %	6.25	5.84	5.89	6.33
Me Pentosan, %	1.85	1.80	1.65	1.25
Alpha, %	76.09	76.83	58.18	57.38
Beta, %	5.93	3.94	26.91	24.75
Gamma, %	17.98	19.23	14.91	17.87

Extractives. A 6-year-old branch contained 3.3% cold water extractives and 11.5% hot water extractives. The unhydrolyzed cold water solution contained 0.3% glucose and 0.3% fructose; the hot water extract had small amounts of arabinose and galactose and a trace of xylose (*10*).

Pulping

Mechanical. The wood is not suitable for mechanical pulp because of its color (*11*).

Sulfite. The wood is reduced with difficulty, and the pulp is fairly strong, very dark in color, and difficult to bleach (*11,12*).

Kraft. The wood is readily reduced, and the pulp is soft, long-fibered, and strong (*11*).

Utilization of Wood and Bark

Use properties of wood. The wood is of moderate weight, strength, hardness, and pliability. Green sapwood is quite moist, and it requires more care and time to kiln dry satisfactorily than do many other conifers. It has moderately low shrinkage. It is among the highest of woods in paint-holding ability. It does not impart taste, odor, or color to food. The heartwood is decay-resistant, while ordinary lumber from second-growth timber is not decay resistant.

Other uses of wood. Most of the baldcypress wood is used for general millwork, containers, caskets, and burial boxes. It is also used for interior trim, paneling, boxes, and crates. Other uses include tanks, vats and tubs, ship and boat building, patterns, flasks, lumber, railway ties, poles, fence posts, piling, cooperage, and shingles.

Heartwood is used principally for building construction, especially for beams, posts, and other members in docks, warehouses, factories, bridges, and various classes of heavy construction. The heartwood is well suited for siding and for porch construction. It is also used for greenhouses, roof planks, cooling towers, and stadium seats.

Physical Properties of Bark

Specific gravity, oven-dry weight & volume (8)	0.55

Literature Cited

1. USDA, Forest Service. Agriculture Handbook No. 445, 1973, 114 p.

2. USDA, Forest Service. Agriculture Handbook No. 271, 1965, 762 p.

3. Timell, T. E. Holz Roh- Werkstoff 30(7):267-73(1972).

4. Thomas, R. J. Wood and Fiber 4(2):87-94(1972).

5. Chang, Y.-P. USDA Tech. Bull. No. 1095, 1954, 86 p.

6. Evert, R. F.; Davis, J. E. *et al.* Planta 95(4):281-96(1970).

7. USDA, Forest Service. Agriculture Handbook No. 72, 1974.

8. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 42 p.

9. Ritter, G. J.; Fleck, R. C. Ind. Eng. Chem. 15:1055-6(1923).

10. Hans, R. Holzforsch. 25(1):15-18(1971).

11. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485, 1927, 101 p.

12. Forest Products Laboratory. USDA Res. Note FPL-031, 1964.

PONDCYPRESS

Scientific Name *Taxodium distichum* var. *nutans* (Ait.) Sweet.

Synonyms Pond baldcypress, black cypress, cypress

Family Name Taxodiaceae

Range Atlantic and Gulf Coastal Plains. Up to 100 ft (30 m) above sea level.

Silvics This tree is confined to the shallow ponds and wet areas of the Coastal Plain, and it generally does not grow in river and stream swamps. The soils in these ponds are usually fine sands, although in some areas there may be a marl underlain by limestone. Pondcypress is often the predominant tree in shallow ponds. Swamp tupelo and baldcypress are its principal associates, and pond pine, spruce pine, and both varieties of slash pine are associated with it at pond borders and in slightly elevated positions within the pond.

Tree Dimensions Not as large as baldcypress.

Gross Features of the Wood Similar to baldcypress.

Microscopic Structure of the Wood Similar to baldcypress.

Gross Features of the Bark Similar to baldcypress.

Physical Properties of Wood Similar to baldcypress.

NORTHERN WHITE-CEDAR

Scientific Name *Thuja occidentalis* L.

Synonyms White-cedar, arborvitae, eastern arborvitae, swamp-cedar

Family Name Cupressaceae

Range Southern Canada, Lake States, Northeast, and Appalachians. The northern white-cedar type occupies 1.9 million acres (770,000 ha) of commercial forest land in the Lakes States (*1*).

Silvics This medium-sized tree has a tapering, usually short bole, a long, dense, irregularly oblong crown, and a shallow, widespreading root system. Northern white-cedar generally grows best on neutral or alkaline soils of limestone origin. It grows both in swamps and on upland soils but does not develop well on extremely wet or extremely dry sites. Most of the commercial stands are found in swamplands which resulted from glaciation. It grows slowly in swamps, but on upland sites the growth rate is more rapid. In suitable locations extensive pure stands develop. In mixed stands, balsam fir, eastern hemlock, white pine, black and white spruces, tamarack, yellow birch, and maples are common associates. The tree bears good seed crops about every 3-5 years, with some production annually. The species is rated as tolerant.

Tree Dimensions 40-50 ft (12-15 m) tall and 2-3 ft (61-91 cm) in diameter.

Pathology

Northern white-cedar is relatively free of disease problems. Butt and root rots do attack the species. Among them are a white, stringy butt rot, *Poria subacida*, and brown cubical rots, *Polyporus balsameus* and *Phaeolus schweinitzii*. These rots are common on trees on swamp knolls or in the drier parts of the swamp (*2*).

Damage by insects is of little economic importance. The black carpenter and (*Camponotus pennsylvanicus*) is among the more serious, attacking the dead heartwood of living trees. The arborvitae leaf miner (*Argyresthia thuiella*) may occasionally infest trees, and those growing on poor sites may die after severe damage.

The species is an important winter browse for deer, and many trees suffer the effects of their feeding.

Gross Features of the Wood The heartwood is straw brown, and the sapwood is nearly white. The wood is very light, soft, usually straight- and even-grained, fine-textured, with a characteristic cedary odor and a faint bitter taste. The earlywood zone comprises most of the growth ring, and the transition to the latewood is more or less gradual. The growth ring is distinct and usually narrow. In the x-section the rays are very fine, and they form a fine, close, inconspicuous fleck on the radial surface. Normal resin canals are absent. Longitudinal parenchyma are not visible with the unaided eye. Behr (*3*) discusses a way of distinguishing heartwood from sapwood.

Microscopic Structure of the Wood

Tracheids. Average, 2.2 mm in length and 20-30 μm in diameter. Weight factor (unbleached kraft) of 0.60. Bordered pits in one row or very rarely paired on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma small, orbicular or nearly so, quite uniform in size (taxodioid), with distinct border and lenticular orifice, 1-4 per cross-field, ray tracheid pits usually absent. Volume occupied, approximately 97%. Root tracheids average 2.1 mm (*4*). Harlow (*5*) found that the rate of increase in tracheid length of trees growing on limestone (good site) was greater with increasing age than that of trees growing in peat (poor site).

Rays. Uniseriate, 1-8+ cells in height, consisting entirely of ray parenchyma or with an occasional ray tracheid, empty or with scanty infiltration, and walls with indentures. Volume occupied, approximately 4%.

Longitudinal Parenchyma. Quite variable in distribution; apotracheal-diffuse, sparse or apparently absent; or abundant and banded in a growth ring and then often absent in adjacent rings.

A recent publication in this area is Keith (*6*).

Gross Features of the Bark The bark is 0.25-0.33 inch (0.6-0.8 cm) thick, reddish to grayish brown, fibrous, forming a network of connecting ridges and shallow furrows, grayish on the surface. Periderm very thin, distinguishable from longitudinal surface by its reddish-brown color; visible under lens in cross section (*7*). Inner bark narrow, usually about 1/16 to 1/8-inch (0.16-0.32 cm) thick; creamy yellow after exposure to air for a short period (*7*). Resin canals in both inner and outer bark, aligned in more or less tangential rows, visible to the naked eye. According to Young (*8*), the bark of various components as a percent of the complete tree bark amounted to: branches and unmerchantable top – 40%, merchantable bole – 38%, and stump and roots – 22%.

Microscopic Structure of the Bark (*7*)

Periderm. Narrow, composed of 2-5 layers of phellem, a layer of phellogen, and about 2-5 layers of phelloderm. Phellem cells thin walled, uniform in thickness; rectangular in cross section, about the same in tangential dimension as parenchyma cells but narrower radially, vertically about 40-50 μm high in radial section. Phelloderm cells about the same size as phellem cells but slightly broader radially. Both phellem and phelloderm cells often contain a resinous substance.

Sieve Cells. Differentiated regularly at every unit of alternate layers of secondary phloem tissues; rectangular in cross section, mostly about 15 and 30 μm in radial and tangential dimensions, respectively, and about 2.5 mm long; usually with chisel-like ends. Sieve cells contain abundant granules of unknown nature.

Phloem Fibers. Differentiated regularly; mature fibers appear at every unit of alternate layers of secondary phloem tissues and remain rather flattened radially throughout inner and outer bark regions. Fibers mostly about the same length and diameter as adjacent sieve cells; ends gradually pointed; cell walls of mature fibers rather thick with a very narrow lumen.

Parenchyma. Parenchyma strands about the same length as adjacent sieve cells. Individual cells about 100-150 μm high. Cells often contain resinous substance and starch.

Rays. Mainly uniseriate, narrow and low; mostly about 6 cells or 150 μm but up to 12 cells or about 200 μm high in tangential section; not much dilated at the outer bark. Cells somewhat rounded on radial end walls; about 20 μm high and 50 μm in radial dimension.

Resin Canals. Vertical resin canals present in both inner and outer bark, aligned more or less in tangential rows; well-defined border formed by thin-walled epithelial cells in 2-5 layers. Canals elliptic and tangentially elongated in cross section; some large-sized ones up to 2 mm in tangential dimension, most about 300 μm in radial dimension, vertically rather high, usually several millimeters long.

Physical Properties of Wood

Specific gravity	Green volume	0.29
	Air-dry volume	0.31
	Oven-dry volume	0.31
Density, lb/cu ft (kg/cu m)	Air-dry	22 (352)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	19 (304)

Percent shrinkage, dried to 0% moisture content: r – 2.2, t – 4.9, v – 7.2.

Percent moisture content, when green

Green basis	35
Oven-dry basis	55

Additional information in this area includes Besley (*9*), Clark and Gibbs (*10*), and Maeglin (*11*).

Physical Properties of Bark

Specific gravity oven-dry weight & volume (*12*)	0.46

Chemical Composition of Wood

Proximate Analyses

	Timell (*13*) (extractive-free wood)	Hyttinen, *et al.* (*14*)
Alpha-cellulose, %	48.9	43.6
Lignin, %	30.7	29.8
Uronic anhydride, %	4.2	–
Alpha-cellulose (corr. for nonglucans), %	45.4	–
Acetyl, %	1.1	–
Ash, %	0.2	0.5
Galactan, %	1.5	–
Glucan, %	45.2	–
Mannan, %	8.3	–
Araban, %	1.3	–
Xylan, %	7.5	–

Holocellulose, %	72.4	58.9
Pentosans, %	–	13.6
Solubility in		
Alcohol-benzene, %	–	6.0
Ether, %	–	1.4
1% NaOH, %	–	12.9
Hot water, %	–	5.3

	Ritter and Fleck (*15*)			
	Sap I	Heart I	Sap II	Heart II
Ash, %	0.64	0.21	0.48	0.27
Solubility in				
Cold water, %	2.18	1.94	3.02	2.80
Hot water, %	2.82	3.22	3.96	4.01
Ether, %	–	–	1.44	1.87
1% NaOH, %	11.02	11.41	12.71	14.14
Acetic acid, %	1.17	0.84	1.11	0.74
Methoxyl, %	5.07	5.00	5.23	5.09
Pentosan, %	11.61	10.79	10.82	10.36
Me Pentosan, %	0.94	1.72	1.16	1.56
C. & B. cellulose, %	55.77	55.19	55.02	54.42
Lignin, %	29.85	31.39	32.14	32.42
In cellulose,				
Pentosan, %	10.35	8.52	8.95	7.97
Me Pentosan, %	1.77	1.58	1.28	1.32
Alpha, %	73.78	61.47	69.17	55.22
Beta, %	0.99	22.23	14.04	24.74
Gamma, %	25.23	16.30	16.79	20.04

Other Information. For information on cyclitols, see Kindl, *et al.* (*16*).

Chemical Composition of Bark

Other Information. For essential elements in bark, see Young (*17*).

Pulping

Kraft. The pulp strength is good, and it is easy to bleach.

Mechanical. The pulp strength is good; color is poor; the pulp is difficult to bleach (*18*).

Sulfite. The pulp strength is good; its brightness and yield are lower than those of spruce.

Utilization of Wood and Bark

Calorific Value of Wood

Million of BTU/air-dry cord	16.3
Million of k cal/air-dry cord	4.1

Literature Cited

1. Ohmann, L. F.; Batzer, H. O.; Buech, R. R.; Lothner, D. C.; Perala, D. A.; Schipper, A. L., Jr.; Verry, E. S. USDA, Forest Serv. Gen. Tech. Rept. NC-48, 1978, 34 p.

2. USDA, Forest Service. Agriculture Handbook No. 271, 1965, 762 p.

3. Behr, E. A. Wood Sci. 6(4):394-5(1974).

4. Fegel, A. C. N.Y. State Coll. For., Tech. Bull. No. 55, 1941, 20 p.

5. Harlow, W. M. Ecology 8:453-70(1927).

6. Keith, C. T. Wood and Fiber 7(2):129-35(1975).

7. Chang, Y.-P. USDA, Tech. Bull. No. 1095, 1954, 86 p.

8. Young, H. E. Forest Prod. J. 21(5):56-9(1971).

9. Besley, L. Pulp Paper Res. Inst. Can., Tech. Rept. No. 489 (Woodlands Res. Index No. 182), 1966, 30 p.

10. Clark, J.; Gibbs, R. D. Can. J. Bot. 35(2):219-53(1957).

11. Maeglin, R. R. USDA, Forest Serv. Res. Pap. FPL-203, 1973, 21 p.

12. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 42 p.

13. Timell, T. E. Tappi 40(7):568-72(1957).

14. Hyttinen, A.; Keller, E. L.; Martin, J. S. USDA, Forest Serv. FPL Rept. No. 2128, 1958, 13 p.

15. Ritter, G. J.; Fleck, L. C. Ind. Eng. Chem. 15:1055-6(1923).

16. Kindl, H.; Kremlicka, G. J.; Hoffman-Ostenhof, O. Monatsh. Chem. 97(6):1783-6(1966).

17. Young, H. E. Forest Prod. J. 21(5):56-9(1971).

18. Schafer, E. R. U.S. Forest Prod. Lab. Rept. No. 2220, 1961, 12 p.

ATLANTIC WHITE-CEDAR

Scientific Name *Chamaecyparis thyoides* (L.) B.S.P.

Synonyms Southern white-cedar, white-cedar, swamp-cedar, false-cypress

Family Name Cupressaceae

Range Narrow coastal belt 50-130 miles (80-210 km) wide, from Maine to Florida and westward to Mississippi.

Silvics White-cedar is usually found on peat deposits but it can grow on wet ground, swamps or sandy soils. The climate is humid and distribution of the species is patchy since suitable sites are not easily available. Atlantic white-cedar characteristically grows in pure stands. However, because of its great range latitudinally, it has been found growing in association with red maple in all sections; blackgum, yellow birch, white pine, and hemlock in New England; blackgum, sweetbay, gray birch, and pitch pine in southern New Jersey; pond pine, slash pine, sweetbay, swamp tupelo, baldcypress, redbay, and loblolly-bay in the South (*1,2,3*). Fair to excellent seed crops are produced each year. The species is rated as very tolerant.

Tree Dimensions 80-85 ft (24-26 m) tall and 2 ft (61 cm) in diameter.

Pathology Resistance to heartwood decay: very high.

The species is not attacked to any degree by disease. A destructive leaf and tip blight is caused by *Didymascella chamaecyparissi*. Atlantic white-cedar is also susceptible to attack by *Armillariella mellea* in the vicinity of hardwood stumps, by *Phaeolus schweinitzii* in various situations involving root injury and by *Heterobasidion annosum* in the vicinity of conifer stumps or other trees already attacked by it (*4*).

White-cedar has no serious insect enemies, although larvae of the common bagworm (*Thyridopteryx ephemeraeformis*) may feed on the foliage (*2*).

Gross Features of the Wood The wood is unusually fine and uniform in texture and generally straight grained. The narrow sapwood is lighter in color than the heartwood and the wood is free from hard deposits, gum and resin. The wood is light, soft, and not as strong as the wood of Alaska-cedar or Port-Orford-cedar and has a slight spicy, aromatic odor.

Miscroscopic Structure of the Wood

Tracheids. Average 2.1 mm in length (*5*).

Gross Features of the Bark (*6*) Outer bark is deep brown with a reddish hue on those regions with exposed periderm. It exfoliates into shallow furrows and long, irregular ridges, often partially connected to each other. Tangentially aligned resin canals are conspicuous in cross section. The inner bark is light yellowish brown with tangential lines of fibers distinct under lens, rather closely spaced. The periderm is inconspicuous in cross section but a deep reddish color on the longitudinal surface. The bark can be peeled off in long, fibrous strips and is often partially twisted around the trunk.

Microscopic Structure of the Bark (*6*)

Periderm. Thin, usually composed of about 5 layers of phellem, a layer of phellogen, and usually 1-2 layers of phelloderm. Phellem cells are thin walled, uniform in thickness, mainly rectangular on radial and cross section, about 40-80 μm high; suberized cells usually contain resinous substances. The phelloderm is slightly broader than the phellem, and cell walls are comparatively thicker.

Sieve Cells. Differentiated regularly and alternately with parenchyma and fibers; about 40 μm in tangential dimension and about 15 μm in radial dimension; about 2.6-3.8 mm long, mostly about 3.4 mm. Sieve cells often contain abundant granules or crystal sands.

Phloem Fibers. Appear rather close to the cambium and alternate regularly with sieve cells and parenchyma strands. Fibers mainly radially flattened, in cross section about 20-30 μm in tangential dimension and about 10-20 μm in radial dimension. Mature fibers occasionally square or slightly radially elongated, ends pointed gradually but sometimes blunt.

Parenchyma. Quite different from that of many other coniferous barks. Strands usually about the same length as adjacent fibers and sieve cells. Individual cells vary from 200-300 μm in height, mostly about 250 μm; in cross section usually about the same shape and size as sieve cells but very often radially expanded to about twice usual size, expansion occurring in the inner bark and sometimes very close to the cambial region. Cells often contain resinous substances.

Rays. Mainly uniseriate, rarely partially biseriate; not much dilated at the outer bark; rather low and narrow on tangential section, mostly about 5-10 cells or 100-200 μm high. Individual cells often contain resinous substances.

Resin Canals. Present without definite location, usually several aligned in a tangential row, some very close to the cambial region; rather large in size, varying from 1/2 to 1 mm in diameter in cross section and vertically up to several mm long.

Physical Properties of Wood

Density, lb/cu ft (kg/cu m) (5)	Oven-dry weight/ green volume	19 (304)

Utilization of Wood and Bark

Use properties of wood. The wood is straight-grained, fine-textured, and low in density. It is moderately soft, weak in bending strength, weak in endwise compression strength, and low in shock resistance. It splits easily, can be finished smoothly, shrinks little, is easily worked with tools, and is very resistant to decay.

Calorific Value of Wood

5040 k cal/kg

Other uses of wood. Most of the wood is used for cooperage (boxes and crates), wood household furniture, primary metal products, and industrial millwork.

Literature Cited

1. Buell, M. F.; Cain, R. L. Ecology 24:85-93(1943).
2. Korstian, C. F.; Brush, W. D. USDA Tech. Bull. No. 251, 1931, 75 p.
3. Little, S. Yale Univ. School Forestry Bull. No. 56, 1950, 103 p.
4. Hepting, G. H. USDA, For. Serv. Agr. Handbook No. 386, 1971, 658 p.
5. USDA, Forest Products Laboratory. USDA, Forest Serv. Res. Note FPL-031, 1964.
6. Chang, Y.-P. USDA, Tech. Bull. No. 1095, 1954, 86 p.

EASTERN REDCEDAR

Scientific Name *Juniperus virginiana* L.

Synonyms Redcedar, red juniper, savin

Family Name Cupressaceae

Range Eastern half of the United States and adjacent Canada; found in every state east of the 100th meridian. The redcedar type covers about 2 million acres (810,000 ha) (*1*).

Silvics Eastern redcedar is variable in form and has a shallow root system. Although it can be found on a variety of soils from dry, rocky soils to swampy land, it grows best on deep, moist, well-drained alluvial soils. Eastern redcedar is drought resistant, cold hardy and stands up well to hot summers. Associated species include shortleaf and Virginia pine in the southern half of its range; and oaks, hickories, black walnut and other hardwoods through the central part of its range. It is also found with gray birch, maple, sassafras, and persimmon. Good seed crops are produced every 2-3 years with light crops in intervening years (*2*). The species is rated as intolerant.

Tree Dimensions Slow-growing and medium-sized tree; 40-50 ft (12-15 m) tall and 12-24 inches (31-61 cm) in diameter. Trees 20-30 years old are generally 18-26 ft (5.5-7.9 m) tall and 2-3 inches (5.1-7.6 cm) in diameter (*1*).

Pathology Resistance to heartwood decay: very high.

The worst enemy of eastern redcedar is fire because of its thin bark and shallow root system.

Rots can be a problem in eastern redcedar, particularly in the south. Its greatest disease enemy throughout much of its range is the root rot, *Heterobasidion annosum*. It can often completely destroy the bark and sapwood of the roots right to the root collar. Other rots of eastern redcedar are the brown cubical rots, *Fomes subroseus* and *Daedalea juniperina*. The species is also a host for the apple cedar rust (*Gymnosporangium* spp.) which is rarely fatal to redcedar but very damaging to apple trees.

There are no serious insect pests of eastern redcedar although it is occasionally attacked by boring insects and bagworms.

Gross Features of the Wood The heartwood is bright red or purplish when first cut, turning dull red or reddish-brown upon exposure to air. The thin sapwood is nearly white. The wood is moderately dense and hard, high in shock resistance and low in strength and stiffness. The grain is usually straight except when deflected by knots, which are common, and fine textured. Shrinkage is small. Longitudinal parenchyma are visible as several dark lines, particularly in the sapwood. The wood has a characteristic cedar odor. McGinnes, *et al.* (*3*) discuss frequency and anatomical features of included sapwood while Kuo and McGinnes (*4*) discuss the structure of false rings.

Microscopic Structure of the Wood

Tracheids. Average 2.8 mm in length (*5*). Lignification during heartwood formation is discussed by Bauch, *et al.* (*6*). McGinnes and Phelps (*7*) found that intercellular spaces occupied approximately 13% of the cross-sectional area of sapwood and 8% of the heartwood. Sastry and Wellwood (*8*) discuss coarseness of earlywood and latewood.

Gross Features of the Bark (*9*) The bark is thin, usually about 1/4-inch (0.64 cm) thick on ordinary-sized trees. The outer bark is yellowish-brown with exposed regions of periderm reddish-brown in color. The outer bark is easily shredded into long, narrow, fibrous strips. The inner bark is about 1/8-inch (0.32 cm) wide, light creamy yellow with a pinkish tinge. Lines of broad fibers are distinct under a lens. Resin canals are present in both the inner and outer bark, aligned more or less in tangential rows and visible to the naked eye.

Microscopic Structure of the Bark (*9*)

Periderm. Thin, composed of 2-5 layers of phellem, a layer of phellogen, and 2-5 layers of phelloderm. Phellem cells are rectangular in cross section, about 10 μm and 20 μm in radial and tangential dimensions, respectively; vertically about 30-50 μm high; thin walled and rather uniform in thickness. Phelloderm cells are slightly broader than phellem cells and usually lignified. Both phellem and phelloderm cells often contain resinous substances, especially in the outer bark region.

Sieve Cells. Differentiated regularly at every unit of alternate layers of secondary phloem tissues; rectangular in cross section, about 20-30 μm and 10 μm in tangential and radial dimensions, respectively, mostly about 2-3 mm long; ends gradually pointed, sometimes blunt. Sieve cells contain abundant granules of unknown nature.

Phloem Fibers. Differentiated at every unit of alternate layers of secondary phloem; conspicuous difference between mature and underdeveloped fibers. Tangentially aligned mature fibers appear at every 3-6 units of alternate layers of secondary phloem tissues; within tangential lines of mature fibers, some immature fibers commonly occur. Fibers are nearly square or radially elongated in cross section; mature fibers have thick, conspicuously lignified cell walls and narrow lumens. Underdeveloped fibers are much thinner walled. Mature fibers average 2.5 mm in length and 30 μm and 20-35 μm in tangential and radial dimensions.

Parenchyma. Parenchyma strands are about the same length as adjacent sieve cells and fibers; radial dimension up to 30 μm in cross section. Individual cells about 50-150 μm high; end walls often rounded. Cells contain resinous substance and starch grains.

Rays. Mainly uniseriate, narrow and low, mostly about 5-8 cells or 100 μm high in tangential section. Individual cells rather small, about 12 μm high and 50 μm in radial dimension, containing resinous substance and starch.

Resin Canals. Present in both inner and outer bark regions, aligned more or less in tangential rows, elliptic and tangentially elongated in cross section. Diameter usually about 200 μm radially, up to 600 or more μm tangentially; mostly over 1/2 cm long; well-formed border of thin-walled epithelial cells in 2-5 or more layers.

Physical Properties of Wood

Density, lb/cu ft (kg/cu m) (*5*)	Oven-dry weight/ green volume	27 (432)

According to McGinnes and Dingeldein (*10*), the mean moisture content of heartwood of 40 standing trees was 22% over a 9-month period.

A bibliography on eastern redcedar has been compiled by Ferguson (*11*).

Utilization of Wood and Bark

Use properties of wood. The wood is moderately heavy, moderately weak, hard, high in shock resistance, and lacking in stiffness. It shrinks very little and stays in place well after seasoning. The texture is fine and uniform. The wood is easily worked and is unequaled for its whittling qualities. Heartwood is very resistant to decay.

Other uses of wood. Most wood is used for fence posts; it is also used for veneer, lumber, kindling, furniture, souvenirs, novelties, and shavings. The wood is also used for cooperage, particularly water buckets. The lumber is used for chests, wardrobes, and closet lining. It is also used for flooring, pencils, scientific instruments, and small boats. The trees are also used for Christmas trees.

Chemical uses of wood. Cedar-wood oil is used in medicine and perfumes.

Chemical uses of leaves. Cedar-leaf oil is used in medicine.

Literature Cited

1. Ferguson, E. R.; Lawson, E. R. USDA, Forest Serv. Publ. No. FPL-260, 1974, 6 p.
2. USDA, Forest Service. Agriculture Handbook No. 271, 1965, 762 p.
3. McGinnes, E. A.; Kandeel, S. A.; Szopa, P. S. Wood Sci. 2(2):100-6(1969).
4. Kuo, M. L.; McGinnes, E. A., Jr. Wood Sci. 5(3):205-10(1973).
5. USDA, Forest Products Laboratory. USDA, Forest Serv. Res. Note FPL-031, 1964.
6. Bauch, J.; Schweers, W.; Berndt, H. Holzforschung 28(3):86-91(1974).
7. McGinnes, E. A., Jr.; Phelps, J. E. Wood Sci. 4(4):225-9(1972).
8. Sastry, C. B. R.; Wellwood, R. W. Tappi 55(6):901-3(1972).
9. Chang, Y.-P. USDA, Tech. Bull. No. 1095, 1954, 86 p.
10. McGinnes, E. A., Jr.; Dingeldein, T. W. Res. Bull. Mo. Agr. Expt. Sta. No. 960, 1969, 19 p.
11. Ferguson, E. R. USDA, Forest Serv. Res. Pap. SO-64, 1970, 21 p.

WESTERN REDCEDAR

Scientific Name *Thuja plicata* Donn ex D. Don

Synonyms Pacific redcedar, giant-cedar, arborvitae, giant arborvitae, canoe-cedar, shinglewood

Family Name Cupressaceae

Range The species grows from the coastal regions of southern Alaska south to northern California. Its easternmost limit is western Montana. It grows from sea level to 4000 ft (1220 m) elevation near the coast and 2000-7000 ft (610-2130 m) in the Rockies.

Silvics This large tree has a broadly buttressed, often fluted base and rapidly tapering bole, an irregular crown, and a shallow, widespreading root system. It generally inhabits moist flats and slopes as well as the banks of rivers and swamps. This species seldom occurs in pure stands, and often makes up 50% of mixed forests. On the coast its important associates are Sitka spruce, western hemlock, Douglas-fir, and grand and silver firs. In the Inland Empire, western larch, western white pine, western hemlock, Douglas-fir, grand fir and Engelmann spruce are its principal associates. This species is a prolific seed producer with heavy cone crops at about 3-year intervals and some production during intervening years. It is a slow-growing, long-lived tree and is tolerant.

Tree Dimensions Large to very large tree and second in maximum trunk diameter. 150-200 ft (46-61 m) tall and 4-8 ft (122-244 cm) in diameter.

Pathology Resistance to decay: durable.

Losses from decay and infection are appreciably higher in the inland areas and include attacks from *Phellinus* (*Poria*) *weirii*, *P. asiatica* and *Phellinus pini*. In the coastal region, fungi of importance include *P. asiatica*, *P. albipellucida* and *Phellinus pini*. Overall, western redcedar is not plagued by disease to the extent its associates are.

The western cedar borer (*Trachykele blondeli*) causes degrade and cull in trees cut for poles, shingles, boats and other products requiring sound wood (*1*). Attacking the bole and large branches are the amethyst cedar borer (*Semanotus amethystinus*) and the western cedar bark beetle (*Phloeosinus punctatus*). Western redcedar has few serious insect enemies as well as few disease problems. Fire is the main enemy of western redcedar.

Gross Features of the Wood The sapwood is nearly white and the heartwood is reddish or pinkish-brown to dull brown. The wood is straight-grained and rather coarse, but fairly even-textured, with a characteristic sweet, fragrant, cedary odor and faint bitter taste. It is moderately soft, dry, light, and weak. Flat grain boards exhibit a distinct but not conspicuous growth ring. The earlywood zone occupies most of the growth ring. The transition from earlywood to the latewood is more or less abrupt, and the latewood is narrow and hard. In the x-section the rays are fine and form a fine, close, inconspicuous fleck on the radial surface. Normal resin canals are absent. Longitudinal parenchyma cells are not visible or barely distinct with a hand lens as a narrow line in the latewood. Sapwood thickness of western redcedar is covered in a publication by Lassen and Okkonen (*2*).

Microscopic Structure of the Wood

Tracheids. Average 3.5 mm (1.4-5.9 mm) in length and 30-40 µm in diameter. Weight factor (unbleached kraft) 0.70 and coarseness of 15.4 mg/100 m. Thin tracheid walls, bordered pits in 1-2 rows on the radial walls; tangential pitting in the last few rows of latewood tracheids; pits leading to ray parenchyma small, orbicular or nearly so, quite uniform in size, with distinct border and lenticular orifice (taxodioid), 1-4 per cross-field; ray tracheid pits usually absent. Volume occupied, approximately 93%.

Rays. Uniserate, 1-12+ cells in height, consisting entirely of ray parenchyma, or rarely with an interrupted row of ray tracheids on margins, and containing a scanty gummy infiltration. Volume occupied, approximately 7%.

Longitudinal Parenchyma. Banded, very variable in distribution.

Gross Features of the Bark Cinnamon-red on young stems, gray on old trunks and forming a closely interlacing network. Fibrous. Double bark thickness averaged 7.2% for coastal western redcedar and 7.9% for interior western redcedar of the diameter outside bark for all sections (*3*).

Microscopic Structure of the Bark

Bark structure similar to that of *T. occidentalis*.

Phloem Fibers. 2.5-3.0 mm long. Mature fibers are squarer in cross section than fibers in the bark of *T. occidentalis* (*4*).

Physical Properties of Wood

Specific gravity	Green volume	0.31
	Air-dry volume	0.33
	Oven-dry volume	0.34
Density, lb/cu ft (kg/cu m)	Green	27 (432)
	Air-dry	23 (368)
	Oven-dry	21 (336)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	19 (304)

Overall increase in specific gravity with increase in height of tree (*5*).

Density 65-71% of density of Douglas-fir (*6*).

Percent shrinkage, dried to 0% moisture content: r – 2.4, t – 5.0, v – 6.8.

Percent moisture content, when green

Green basis	27
Oven-dry basis	37

Percent moisture content, oven-dry basis (*7*)

Heartwood	58
Sapwood	249

Additional information in this area includes Bendtsen (*8*) and Maeglin and Wahlgren (*9*).

Physical Properties of Bark

Specific gravity, oven-dry weight & volume (*10*)		0.44
Specific gravity, green volume (*11*)	Inner bark	0.36
	Outer bark	0.38
Percent moisture content, oven-dry basis (*11*)	Inner	88
	Outer	37

Chemical Composition of Wood

Proximate Analyses

	F.P.L.	Wise and Ratliff (*12*) Series A	Wise and Ratliff (*12*) Series B	Thomas and Davis (*13*)
Lignin, %	31.8	32.5	32.5	28.9
Alpha-cellulose, %	38.0	52.7	47.5	–
Hemicellulose, %	–	14.65	–	–
Ash, %	0.3	0.27	0.27	0.32
Pentosans				
Total, %	9.0	–	–	–
In cellulose, %	6.9	–	–	–
Mannan, %	–	–	5.1	12.4
Acetyl, %	–	0.53	0.53	–
Xylan (corr. for uronic anhydride), %	–	–	8.1	7.3
CH_2 (from MeO not in lignin), %	–	–	0.22	–
Total cellulose, %	48.7	–	–	–
Solubility in				
Alcohol-benzene, %	14.1	–	–	–
Ether, %	2.5	–	–	0.7
1% NaOH, %	21.0	–	–	–
Hot water, %	11.0	–	–	5.9

Uronic anhydride, %	–	–	4.2	–
Alcohol-benzene solubles, %	–	–	–	3.3
Cold water solubles, %	–	–	–	3.7
Silica, ppm	–	–	–	33.0
S. G., gm/cc	–	–	–	0.303
Arabinan, %	–	–	–	1.5
Galactan, %	–	–	–	2.05

For information on hemicelluloses, see Dutton and Funnell (*14*).

Extractives. Successive extractions reported by Lewis (*15*) showed water solubles, 7.33%, ether solubles, 0.31%, and alcohol solubles, 2.56%; total 10.2%.

Steam distillation gave 0.03-0.30% of thujic acid (dehydroperillic acid), $C_{10}H_{12}O_2$, m.p. 88°. A second compound, $C_{10}H_{12}O_2$, m.p. 82° (now termed o-thujaplicin), which is very toxic to *Heterobasidion annosum*, has also been isolated (*16,17*).

Further study has isolated three phenolic compounds with the same general formula. These appear to be hydroxyketones, containing in each case an isopropyl group attached to a seven-membered ring. They have been termed α-, β-, and o-thujaplicin. All are highly toxic toward wood-destroying fungi (*18-20*).

Kurth (*21*) reports that the methyl ester of dehydroperillic acid is probably the chief odoriferous constituent of this species.

Small amounts of pectic substances have been found (*22*).

For information on resin acids and fatty acids, see Swan (*23*).

Chemical Composition of Bark

Proximate Analysis

	Thomas and Davis (*13*)
Lignin, %	31.0
Ash, %	1.95
Mannan, %	11.0
Xylan, %	9.15
Ether, %	5.8
Hot water, %	7.7
Alcohol-benzene, %	7.4
Cold water, %	3.3
Silica, ppm, %	134.0
S. G., gm/cc, %	0.317
Arabinan, %	4.60
Galactan, %	4.10

Extractives. For compounds in bark, including a diterpene, and neutral extractives, see Quon and Swan (*24,25*).

Pulping

Two-stage alkaline sulfite/oxygen. Yields are up to 17% higher than with kraft pulping and duplex linerboards have better strength and brightness (*26*).

Kraft. The wood is readily reduced; yield is low; the pulp forms exceptionally well on the paper machine; its color is dark, and it is bleached with difficulty (*27-30*). The wood can be pulped by the hydrogen sulfide kraft process (*31*). Bleached pulps can be made from sawdust by the prehydrolysis kraft process or presteam kraft process. Although the pulp has superior strength properties for some uses, its value does not compensate for the disadvantages (*32*).

Magnefite. The wood can be pulped by the Magnefite process by direct steaming in the vapor phase.

Mechanical. The pulp is too dark (*32*).

Nitric acid. The wood can be pulped by the nitric acid process to a relatively high yield (*33*).

Two-stage soda-oxygen. Reduction of kappa no. from 180-120 lowered the oxygen consumption in the second stage without significantly affecting the properties of pulps delignified to a final permanganate no. of 22 (*26*).

Sulfite. The alkaline sulfite/oxygen pulping of chips gives higher yield and superior bottom linerboard properties compared to conventional kraft pulp. Sodium sulfite pulping followed by oxygen-alkali delignification gives pulps of higher yield than kraft; duplex linerboards were equivalent to kraft or better (*34*). The wood is reduced with difficulty, it is shivy, dark in color, difficult to bleach, and the yield is slightly low (*35,36*). Ten per cent bark may be used.

Yield is low, color is poor, chemical consumption is high, drainage is poor, and there are extreme barking difficulties (*32*).

Other Information. The stringy bark complicates pulping. Corrosion (by volatile tropolones and nonvolatile phenolic compounds reacting with iron or iron oxides) is a disadvantage (*32*).

Utilization of Wood and Bark

Use properties of wood. The wood is generally straight-grained, has a fairly uniform but rather coarse texture, and it has the aromatic odor characteristic of the cedars. It has a very small shrinkage and is free from pitch. It is light in weight, moderately soft, weak when used as a beam or post, and low in shock-resisting ability. It is highly decay resistant, holds paint very long, and is weather-resistant. It is not difficult to kiln dry. Dried wood stays in place well. It has a tendency to split when nailed. The wood can be easily glued with different glues under a wide range of conditions.

Calorific Value of Wood

Million of BTU/air-dry cord	16.8
Million of k cal/air-dry cord	4.2

9700 BTU/lb heating value for moisture-free wood
5389 k cal/kg heating value for moisture-free wood

Calorific Value of Bark

4830 kg cal/kg

Chemical uses of wood. An aqueous extract applied to the surface of ferrous metals produces a reaction coating which imparts corrosion resistance and enhances adhesion between metal and paint (*37*).

Other uses of wood. The wood is used for split products, decorative plywood, and face laminate for roof decking. It is also used for telephone and transmission poles, wooden pipe and tanks, outdoor patio construction, boat planking, and wood covering for veneer in racing shells.

Other uses of bark. The bark is used for boards.

Literature Cited

1. Furniss, R. L.; Carolin, V. M. USDA, Forest Serv. Misc. Publ. No. 1339, 1977, 654 p.
2. Lassen, L. E.; Okkonen, E. A. USDA, Forest Serv. Res. Pap. FPL-124, 1969.
3. Smith, J. H. G.; Kozak, A. Mimeo of "Thickness and percentage of bark of the commercial trees of British Columbia," University of British Columbia, Faculty of Forestry, 1967.
4. Chang, Y.-P. USDA Tech. Bull. No. 1095, 1954, 86 p.
5. Okkonen, E. A.; Wahlgren, H. E.; Maeglin, R. R. Forest Prod. J. 22(7):37-42(1972).
6. Wethern, J. D. Can. Pulp Paper Ind. 12(9):23-8(1959).
7. U.S. Forest Products Laboratory. Agriculture Handbook No. 72, 1974.
8. Bendtsen, B. A. USDA, Forest Serv. Res. Pap. FPL-191, 1972, 17 p.
9. Maeglin, R. R.; Wahlgren, H. E. USDA, Forest Serv. Res. Pap. FPL-183, 1972.
10. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969.
11. Smith, J. H. G.; Kozak, A. Forest Prod. J. 21(3):38-40(1971).
12. Wise, L. E.; Ratliff, E. K. Anal. Chem. 19:459(1947).
13. Thomas, P. R.; Davis, R. E. Pulp Paper Mag. Can. 75(3):60-3(March 1974).
14. Dutton, G. G. S.; Funnell, N. A. Can. J. Chem. 51(19):3190-6(Oct. 1, 1973).
15. Lewis, H. F. Tappi 33:299(1950).
16. Anderson, A. B.; Sherrard, E. C. J. Am. Chem. Soc. 55:3813(1933).
17. Gripenberg, J. Acta Chem. Scand. 3:1137(1949).
18. Anderson, A. B.; Gripenberg, J. Acta Chem. Scand. 2:644(1948).
19. Erdtman, H.; Gripenberg, J. Nature 161:719(1948).
20. Gripenberg, J. Acta Chem. Scand. 2:639(1948).

21. Kurth, E. F. J. Am. Chem. Soc. 72:5788(1950).

22. Anderson, E. J. Biol. Chem. 165:233(1946).

23. Swan, E. P. Can. Dept. For. Inform. Rept. VP-X-115, 24 p. Aug. 1973.

24. Quon, H. H.; Swan, E. P. Can. J. Chem. 47(23):4389-92(Dec. 1, 1969).

25. Quon, H. H.; Swan, E. P. Can. Dept. For. Bimo. Res. Note 28(4):23-4(July/Aug. 1972).

26. Worster, H. E. Pulp Paper Poll. Abatement Proj. Rept. 13-1, 16 p. Mar. 31, 1971.

27. Bray, M. W.; Martin, J. S. Tech. Assoc. Papers 30:388(1947); Paper Trade J. 125(16):40(Oct. 16, 1947).

28. Hatch, R. S.; Holzer, W. F. TAPPI Monograph No. 4:153(1947).

29. Holzer, W. F.; Booth, K. G. Tappi 33:95(1950).

30. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. 1485. May, 1927. 101 p.

31. Vinje, M. G.; Worster, H. E. Tappi 53(6):1082-6(June, 1970).

32. Wethern, J. D. Can Pulp Paper Ind. 12(9):23-4,26,28,32(Sept. 1959).

33. Walter, H. K. TAPPI/CPPA Intern. Sulfite Pulping Recovery Conf. (Boston), Oct.-Nov. 1972:181-96.

34. Worster, H. E.; Pudek, M. F. Tappi 57(3):138-41(March, 1974).

35. Holzer, W. F.; Booth, K. G. Tappi 33:95(1950).

36. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. 1485. May, 1927. 101 p.

37. Kronstein, M.; ITT Rayonier Inc. U.S. pat. 3,547,710. Issued Dec. 15, 1970. 16 claims.

INCENSE-CEDAR

Scientific Name *Calocedrus decurrens* Torr.

Synonyms California incense-cedar

Family Name Cupressaceae

Range Central Oregon to Lower California; 1200-9000 ft (370-2740 m) above sea level.

Silvics The mature tree has a rapidly tapering bole which is often fluted and broadly buttressed at the base, an irregular, often deformed crown, and a well-developed, moderately deep, lateral root system. It grows best on cool, moist sites in the transition zone of the central Sierra Nevada. It is found in mixture with sugar pine, ponderosa pine, western white pine, white fir, giant sequoia, and Douglas-fir. Although a prolific seed producer, good crops occur only at intervals of 3-6 years. This species is rated as tolerant.

Tree Dimensions 75-110 ft (23-34 m) tall and 3-4 ft (91-122 cm) in diameter.

Pathology

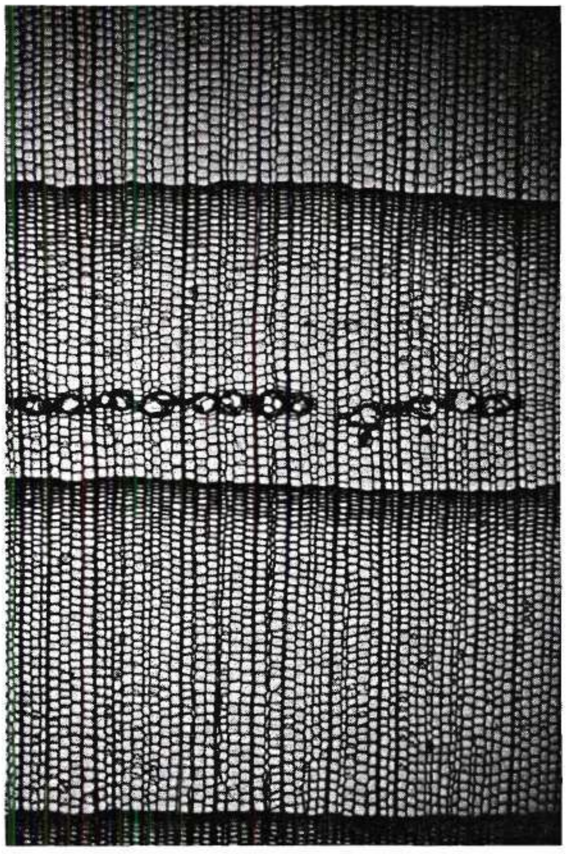
The only foliage rust of any importance is *Gymnosporangium libocedri,* which causes stem and branch swellings and kills small sprays of foliage. An important cause of cull in incense-cedar is the pecky dry rot (*Polyporus amarus*), and its only host is incense-cedar. It enters through wounds and branch stubs and causes a brown pocket dry rot. The mistletoe pest of incense-cedar is *Phoradendron juniperinum* subsp. *libocedri*.

Little economic loss is caused by insects. However, the species is attacked by a number of borers. Among these are the western cedar borer (*Trachykele blondeli*), the flatheaded borer (*T. opulenta*), the amethyst cedar borer (*Semanotus amethystinus*), the cedar flatheaded borer (*Chrysobothris nixa*) and the western cedar bark beetle (*Phloeosinus punctatus*).

Gross Features of the Wood The sapwood is nearly white to cream colored and the heartwood is reddish brown to dull brown, sometimes with a lavender tinge. The wood is light, moderately soft, straight- and even-grained, medium-textured, with a characteristic pungent odor and spicy acrid taste. The earlywood zone is usually broad, and the latewood zone is fairly conspicuous and narrow. The transition from earlywood to latewood is gradual. The growth rings are distinct and quite uniform in width. In the x-section the rays are fine, plainly visible with a hand lens, and form a fine, close fleck on the radial surface. Normal resin canals are absent. Longitudinal parenchyma cells are very abundant and, while scattered and difficult to see even with a hand lens in the earlywood, they are often banded in the latewood and readily visible with a hand lens or even without magnification. Brown masses of decayed wood, known as peckiness, are often present.

Microscopic Structure of the Wood

Tracheids. Average 3.6 mm in length and 35-40 μm in diameter. Bordered pits in 1-2 rows on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma small, oval, quite uniform in size (cupressoid), with distinct border and lenticular orifice, 1-4 (generally 1-2) per cross-field; ray tracheid pits occasionally present. Volume occupied, approximately 90%.



Cross section of incense cedar, showing gradual transition from earlywood to latewood. Traumatic resin canals are present. Magnification 20X.

Rays. Uniseriate or in part biseriate, consisting entirely of ray parenchyma or with occasional ray tracheids, up to 15+ cells in height, containing dark gum in the heartwood. Volume occupied, approximately 9%.

Longitudinal Parenchyma. Apotracheal-diffuse, solitary, 2 to several contiguous tangentially, and in interrupted bands in the outer latewood; with dark gummy contents. Volume occupied, <1%.

Gross Features of the Bark Thin, smooth, and gray-green or scaly and tinged with red on young stems; 3-8 inches (8-20 cm) thick, yellowish-brown to cinnamon-red, fibrous, deeply and irregularly furrowed on old trunks. Inner bark mostly about 1/4-inch (0.6 cm) wide; much lighter in color than outer bark; expanded parenchyma layers occur in the outer part of the inner bark, usually about 2-4 expanded layers mixed with regular compact layers of secondary phloem tissues, distinct under lens (*1*).

Microscopic Structure of the Bark (*1*)

Periderm. Narrow, composed of about 5 layers of phellem, a layer of phellogen and 2-5 layers of phelloderm. Phellem cells thin walled and uniform in thickness. Phelloderm cells are about the same shape as phellem cells but are smaller in size. Cells in old bark often become lignified and contain a resinous substance.

Sieve Cells. Differentiated regularly between a layer of parenchyma and a layer of fibers; about 40-50 μm in tangential dimension and 30 μm in radial dimension; varying from 2.6-4.5 mm in length, mostly about 3.7 mm; ends gradually pointed, chisel-like, or sometimes blunt. Small granules of unknown nature appear in sieve cells in the inner bark.

Phloem Fibers. Appear regularly in every unit of alternate layers of secondary phloem tissue; slightly variable in size and thickness of cell walls. In young stems, fibers regular and uniform in size and shape, conspicuously flattened radially. In old barks, mature fibers appear every two units of alternate layers of secondary phloem tissues, flattened radially in those cells close to the cambium. Fibers in the inner bark are about the same length as sieve cells; ends usually pointed but slightly curved and blunt ends not uncommon. Cell walls very thick and with a very narrow lumen in mature fibers. Fibers in the outer bark are comparatively shorter than those in the inner bark, mostly about 3 mm long.

Parenchyma. Parenchyma strands differentiated regularly in alternating sequence with sieve cells and phloem fibers. Cells contain a resinous substance and starch grains. Conspicuously radially expanded parenchyma cells occur in the outer part of the inner bark, mixed with layers of regularly grown tissues; expansion may extend to 5-10 times original radial dimension and 2-4 times original tangential dimension, as shown on cross section. Adjacent tissues are obliterated and cell walls of expanded cells are comparatively thicker than usual.

Rays. Mainly uniseriate, occasionally partially biseriate; mostly 10-15 cells or 300 μm but up to 25 cells or 600 μm high, tangentially about 15 μm wide in the inner bark, not much dilated towards the outer bark. On radial section, individual cells are about 40-60 μm high and about 150-200 μm in radial dimension and contain a resinous substance and starch grains.

Resin Canals. Occur in both the inner and outer bark; oval to elliptic in cross section, with a tangential diameter of about 500 μm; canal borders well defined by thin-walled epithelial cells.

Physical Properties of Wood

Specific gravity	Green volume	0.35
	Air-dry volume	0.37
	Oven-dry volume	0.38
Density, lb/cu ft (kg/cu m)	Air-dry	25 (400)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	22 (352)

Percent shrinkage, dried to 0% moisture content: r – 3.3, t – 5.2, v – 7.6.

Percent moisture content, when green

Green basis	52
Oven-dry basis	108

Percent moisture content, oven-dry basis (*2*)

Heartwood	40
Sapwood	213

Physical Properties of Bark

Specific gravity oven-dry weight & volume (*3*)	0.27

Chemical Composition of Wood

Proximate Analyses

	Ritter and Fleck (*4*)	Ritter and Fleck (*5*) Sapwood	Ritter and Fleck (*5*) Heartwood
Lignin, %	37.68	34.73	33.67
C. & B. cellulose, %	41.60	49.09	44.53
In cellulose			
Pentosan, %	9.08	10.14	11.68
Me Pentosan, %	1.99	1.24	1.31
Alpha	46.92	50.69	66.62
Beta	11.67	12.98	11.05
Gamma	41.06	36.33	22.33
Ash, %	0.34	0.47	0.30
Pentosan, %	10.65	12.08	12.04
Acetic acid, %	0.91	1.33	0.68
Methoxyl, %	6.24	5.95	6.21
Solubility in			
Cold water, %	3.64	1.92	4.74
Hot water, %	5.38	2.97	7.08
Ether, %	4.31	0.67	4.78
1% NaOH, %	17.69	11.16	19.99

Extractives

Glucose, fructose, sucrose, raffinose, and a trace of stachyose are found in an alcohol extract of sapwood; arabinose and a trace of glucose, galactose, xylose, rhamnose, and fucose, in the heartwood (*6*). The extraneous substances in the sapwood average 3.4% and in the heartwood 14.7% (*7*). The distribution of ether, alcohol, hot water, and total extractives has been determined for sapwood and heartwood in the top, middle, and base for several mature trees (*7*). The sapwood has 0.2% petroleum ether solubles, 1.8% phlobaphenes and tannins, and 1.4% carbohydrates and cyclitols; the heartwood contains 4.7% petroleum ether solubles, 8.0% hot water solubles, and 5.7% cold water solubles (*7*).

The heartwood extractives have been studied in considerable detail, especially so because of their relation to decay resistance (*7,8*). Exhaustive acetone extraction at room temperature yielded 17.9% crude extract which was further fractionated. There were small amounts of terpenes, thymoquinone (0.10%), tropolones, and carbohydrates; the extractives were chiefly phenolic in nature. About 23-24% of the extractives had the basic *p*-cymene skeleton, 55-60% were phlobaphenes, and 10-15% tannins (*7*). Tannins amounted to 2-3% of the dry weight of the heartwood.

Pulping

Kraft. The wood is readily reduced; the pulp is fine fibered and very strong (*9,10*).

Sulfite. The wood is fairly readily reduced; the pulp is very dark and is bleached with difficulty (*9,10*).

Mechanical. The pulp is dark (*10*); it has a high content of fines and is weak (*11*).

Refiner groundwood. The pulp has poor brightness and strength and a high content of fines (*11*).

Literature Cited

1. Chang, Y.-P. USDA, Tech. Bull. No. 1095, 1954, 86 p.

2. USDA, Forest Service. Agriculture Handbook No. 72, 1974.

3. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 42 p.

4. Ritter, G. J.; Fleck, L. C. J. Ind. Eng. Chem. 14(11):1050-4(1922).

5. Ritter, G. J.; Fleck, L. C. Ind. Eng. Chem. 15:1055-6(1923).

6. Smith, L. V.; Zavarin, E. Tappi 43(3):218-21(1960).

7. Zavarin, E. Calif. Forestry & Forest Prod. No. 5, 1958.

8. Anderson, A. B.; Zavarin, E. J. Inst. Wood Sci. 15:3-24(1965).

9. Forest Products Laboratory. U.S. For. Serv. Res. Note No. FPL-031(1964).

10. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485, 1927.

11. Braun, R. V.; Davis, J. W. Tappi 52(2):282-8(1969).

SCOTCH PINE

Scientific Name *Pinus sylvestris* L.

Synonyms Scots pine, Baltic redwood, yellow deal

Family Name Pinaceae

Range Native of Eurasia. Extensively planted and naturalized locally in southeastern Canada and northeastern United States.

Silvics A very important tree in its native habitat. Trees in closed stands produce straight and clean trunks with little taper and a short compact crown. The origin of the seed is of great importance, and many of the plantation trees in this country have obtained a poor reputation because of the crookedness of the young boles. The species thrives on poorer, sandy soils as well as better loams. Scotch pine is rated as very intolerant. Native American pines are usually superior for forestry purposes.

Tree Dimensions 70-80 ft (21-24 m) tall and 18-36 inches (46-91 cm) in diameter.

Pathology

Scotch pine is subject to many insect and disease problems. One disease of recent interest in this country has been scleroderris canker (*Gremmeniella abietina* = *Scleroderris lagerbergii*). Originally, the disease was only serious on juvenile trees but now poses a threat to trees of all ages. The disease is controlled by planting disease-free trees in areas where no infected trees are present. Scotch pine is susceptible to several rusts, including comandra blister rust (*Cronartium comandrae*), sweet-fern blister rust (*C. comptoniae*) and western gall rust (*Peridermium harknessii*). The white stringy root rot (*Heterobasidion annosum*) also attacks Scotch pine as does the brown spot needle blight (*Scirrhia acicola*). The latter disease can leave seedlings with greatly reduced leafage, resulting in death or retarded growth.

Scotch pine is frequently attacked by the white-pine weevil (*Pissodes strobi*), with considerable damage found in Canada. Heavy feeding partially girdles the terminal stem, greatly reducing growth. The species is also a favored host of the pine root collar weevil (*Hylobius radicis*) which injures the bark and cambium around the roots and root collar. It is also a preferred host of the pine tortoise scale (*Toumeyella numismatica*) and the Nantucket pine tip moth (*Rhyacionia frustrana*). Damage from the European pine sawfly (*Neodiprion sertifer*) can be severe with heavily defoliated trees weakened and rendered susceptible to insect attack. Zimmerman pine moth (*Dioryctria zimmermani*) damage is especially serious in Christmas tree plantations. Scotch pine is also the favorite host of the pine spittlebug (*Aphrophora parallela*) and attacked trees may be severely stunted or killed.

Gross Features of the Wood The sapwood is nearly white to yellowish or reddish white, and the heartwood is brownish red. The wood is moderately hard, moderately heavy, medium textured, with a distinct resinous, noncharacteristic odor, and without a characteristic taste. The transition from earlywood to latewood is abrupt, but the widths of each vary within wide limits. A distinct growth ring figure is present. Rays are very fine and are not visible with the unaided eye except where they include a horizontal resin canal, forming a fine, close, inconspicuous fleck on the radial surface. Both longitudinal and horizontal resin canals are present. The longitudinal ones appear as whitish or brownish flecks in the x-section, conspicuous or relatively conspicuous with the unaided eye, plainly distinct with a hand lens, numerous, confined largely to the central and outer portions of the growth ring, solitary or rarely 2-3 contiguous in a tangential line, generally visible as relatively inconspicuous streaks along the grain. Horizontal rays are less conspicuous and appear as whitish, relatively inconspicuous wood rays spaced at irregular intervals on the transverse surface. Longitudinal parenchyma cells are absent. In 45-year-old trees, the amount of branchwood without bark and needles, expressed as a percent of dry stemwood without bark was 13.5% (*1*).

Microscopic Structure of the Wood

Tracheids. Average, 1.8-4.4 mm in length and 38 μm in width; wall thickness 2-10 μm; lumen diameter, radial, earlywood, 10-50 μm, latewood, 3-20 μm; tangential, earlywood, 10-50 μm, latewood, 4-40 μm. Volume occupied, 93%. Windowlike. According to Oniski and Wojno (*2*), the fiber length along the trunk of 25-year-old trees averaged 1-2.5 mm *vs.* 3.5 mm for 105-year-old trees. In both age groups, fibers at the top of the trunk tended to be longer than those at the base. A highly significant, linear relationship was found between wood density and tracheid length, tree height and tracheid length, and width of the growth ring and tracheid length (*3*). In another study (*4*), the correlation of growth rate with tracheid length was found to be caused by differing tracheid lengths among different provenances and not by growth rate *per se.* Schultze-Dewitz (*5*) found that, for a given tree height, tracheid length increased with tree age up to 60-80 years, beyond which it tended to level off.

Resin Canals. Longitudinal, average, 100 μm in diameter; horizontal canals are smaller; thin-walled epithelial cells; tylosoids present in the heartwood. Volume occupied, 0.4-1.4%.

Rays. Two types, uniseriate and fusiform; the uniseriate are numerous; the fusiform are scattered and up to 25 cells high, several seriate in the central portion which includes a horizontal resin canal, tapering to uniseriate at the margins; ray tracheids occur in both types of rays, marginal and interspersed, dentate inner walls. Thin-walled ray parenchyma. Volume occupied, approximately 6%. Karkainen (*6*) found the size and number of rays were greatest at the stump level, decreasing in some cases right to the top of the tree. The ratio of fusiform to uniseriate rays was 1:40-1:50. Another publication in this area is Nyren and Back (*7*).

Longitudinal Parenchyma. Absent.

Additional publications in this area include Babos (*8*), Boutelje (*9*) and Greaves (*10*).

Gross Features of the Bark On the trunk, the bark is scaly and peels off in flakes from the ridges, which are separated by long, shallow fissures. The lower part of the trunk is rough while the upper is rather smooth and distinctly orangish in color. The outside bark on the lower trunk is grayish-brown while the inner is reddish-brown. In relation to the weight of green, unbarked logs, the proportion of green bark averaged 8-9% (*11*). Two 60-year-old stands were treated with various combinations of N,P,K and Ca. Nitrogen was the only nutrient that affected bark percent, which was lower in fertilized plots. The decrease was about 1% in trees 10 m tall and 0.5% in trees 20 m tall (*12*). Other publications in this area include Grochowski (*13*) and Korsun (*14*).

Physical Properties of Wood

Specific gravity	Oven-dry volume	0.49
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	26 (416)

According to Klem (*15*), fertilization caused only minor changes in wood properties. The most significant was a 5% drop in specific gravity. Similar results were obtained from thinning.

Hakkila (*1*) found that the average density of branchwood was 416 kg/cu m.

According to Pechmann and Wutz (*16*), the densest wood usually occurred in rings 1-1.5 mm wide and, as long as fertilizing did not increase ring width greatly above this, no reduction in wood density should be feared.

A highly significant linear relationship was found between wood density and d.b.h., and wood density and tracheid length. The correlation between wood density and width of the growth ring was significant at the 2.5% level (*3*).

Dorn (*4*) found that the significant interaction of growth rate with provenance and with age suggests that growth rate affects specific gravity more in some provenances than others and more during certain periods of the tree's life.

Percent shrinkage, dried to 0% moisture content: r – 4.0, t – 7.7, v – 12.4.

Physical Properties of Bark

Moisture content increased with decreasing bark thickness from the stem base to the top, and average values varied during the year from 109% to 161% (mean 133.5%) (*17*).

Additional information can be found in Dietz (*18*).

A comprehensive monograph on Scotch pine has been compiled by Alexe (*19*).

Chemical Composition of Wood

Proximate Analyses

	Colombo, *et al.* (*20*)	Corbetta (*21*) France	Corbetta (*21*) Finland	Croon (*22*)
Klason lignin, %	27.3	24.86	25.50	27 (extr.-free wood)
Alpha cellulose, %	56.4	45.40	46.08	41
Ash, %	0.3	0.28	0.21	–
Pentosans, %	10.2	8.93	8.71	–
Xylan, %	–	–	–	12
Galactan, %	–	–	–	2
Glucomannan, %	–	–	–	18

Solubility in				
Alcohol-benzene, %	2.8	6.00	4.50	–
Cold water, %	0.3	1.20	1.38	–
Hot water, %	2.0	2.06	1.73	–
1% NaOH, %	9.5	11.75	10.10	–

	Sharkov (*23*)
Lignin, %	27.3
Alpha-cellulose, %	36.9
Ash, %	0.2
Mannan, %	9.6
Acetic acid, %	1.1
Xylan, %	6.35
Galactan, %	3.0
Araban, %	4.15
Uronic acid, %	2.8
Protein, %	0.4
Fats, resins, %	2.0

A comprehensive analytical study of wood samples obtained from various forest types was made as well as analyses of wood taken at different heights in the same tree, and of the heartwood and sapwood of individual logs (*24*). Despite the rather wide analytical fluctuations, the following "typical analysis" is given: 44.8% pure cellulose; 4.3% hemicelluloses (comprising 1.7% xylan, 2.2% mannan, and 0.4% levulan, which would normally be retained in what is ordinarily called alpha-cellulose); 14.6% readily hydrolyzable hemicelluloses (5.5% xylan, 5.4% mannan, 1.3% galactan and 2.4% uronic acids) 5.7% resins, 1.37% acetyl, 0.23% formyl; 0.35% ash; 0.9% protein; and 27.8% lignin.

Aurell (*25*) reports the following analysis: 4% extractives, 27% lignin, 17% glucomannans, 10% xylan, and 39% alpha-cellulose.

Extractives. Pinosylvin monomethyl ether, pinosylvin, pinocembrin, and pinobanksin occur in the heartwood (*26*).

Mirov (*27*) presents analytical data determined by several investigators prior to 1961 on the composition of gum turpentine. Although considerable quantitative variation exists, d-α-pinene was present in the greatest amount, followed by d-Δ^3-carene, ℓ-β-pinene, limonene. Wood turpentine contained these constituents also. d-Δ^3-Carene has also been reported as the chief component of turpentine from steam distillation of stumpwood (*28*).

Copaborneol is the major sesquiterpene alcohol in the wood (*29*).

Fresh pinewood contained 3.10% acetone extractives, including 2.42% ether solubles and 0.68% ether insolubles. Petroleum ether solubles were 2.29%, composed of 7.55% free fatty acids, 29.03% resin acids, and 60.59% neutral components, expressed as percentage of the petroleum-ether solubles (*30*).

Thielges (*31*) reports the phenolic content higher in the outer heartwood than in the center.

Other Information. Volatile substances, mainly hydrocarbons, have been identified by Donetzhuber, *et al.* (*32*).

Pulping

Kraft. The wood is readily reduced, and the pulp is of good strength (*33*). Other references in this area include Aurell (*34*), Colombo, *et al.* (*35*), Dillen and Noreus (*36*), Farkos and Jaros (*37*), Gugnin (*38*), Hartler (*39*), Jarvela and Makkonen (*40*), and Mannbro (*41*).

Sulfite (*Ca-base*). The wood is reduced with difficulty and very unevenly; the pulp is of fair color but shivy (*33,42,43*). Although sapwood is readily pulped, heartwood gives problems (*44-46*). For *NH_4-base* sulfite pulping, see Eliashberg and Tsypkina (*47*) and Zhigirzhi and Kudryavtseva (*48*). For *Mg-base* pulping, see Bitschman, *et al.* (*49*) and Hemingway and Hillis (*50*).

Hydrogen Sulfide/Kraft. The concentration of NaHS in the pretreatment liquor strongly affects the yield increase because of the buffering HS^- ions. The greatest yield increase was at an NaHS-concentration of 0.1*M*; the partial pressure of H_2S also influenced the yield. The total yield increased with increasing pressure and reached a plateau at about 5 atm., measured at room temperature (*51*).

Polysulfide. These pulps were easier to beat and had higher breaking length than conventional sulfate pulps; tearing strength at the same breaking length was somewhat lower for polysulfide pulps (*52*). Polysulfide cooks were more easily controlled than kraft cooks, and the process offers the advantages of yield increases plus the possibility of attaining a higher pulp viscosity in cooks to low kappa numbers than conventional kraft (*36*). See also Aurell and Hartler (*53*), Jarvela and Makkonen (*40*) and Kinzner (*54*).

Mechanical. This pulp is probably similar to that of jack pine (*33*). The pulp is of higher yield and is freer than that of Norway spruce (*55*) but poorer in strength and color (*56-58*).

Refiner Groundwood. Best results were obtained at a sulfidity of 12-15% (*59*). The process would benefit from a very mild chemical pretreatment (*60*). See also Packman (*61*).

Steamed Groundwood. This process has lower power consumption, increased yield, and higher strength than the regular groundwood process (*62*).

Two-stage bisulfite. The pulp is brighter, softer, more easily beaten, and has better sheet formation than kraft but a lower tear factor; yield is ca. 15% greater than kraft and 5-10% greater than standard sulfite (*63-66*).

Phenol. This process can be used (*67*).

Utilization of Wood and Bark

Other uses of wood. Particle boards can be made from chips sprayed with a wax emulsion and bonded with glues; boards made with polyphenolics will withstand 2 years of outdoor weathering.

Literature Cited

1. Hakkila, P. Commun. Inst. For. Fenn. No. 67.6, 1969.
2. Oniski, W.; Wojno, P. Przeglad Papier. 25(7):228-30(1969).
3. Echols, R. M. Yale Univ., School of Forestry, Bull. No. 64, 1958, 52 p.
4. Dorn, D. *In* Proc. 16th Northeastern Forest Tree Improvement Conf., Aug. 8-10, 1968, Quebec, Canada, p. 1-6.
5. Schultze-Dewitz, G. Holz-Roh- Werkstoff 23(3):81-6(1965).
6. Karkkainen, M. Silvae Fennica 7(2):69-95(1973).
7. Nyren, V.; Back, E. Norsk Skogind. 8:267-78(1959).
8. Babos, K. Holztechnol. 14(4):203-7(1973).
9. Boutelge, J. B. Svensk Papperstidn. 69(1):1-10(1966).
10. Greaves, H. Holzforschung 27(3):80-8(1973).
11. Volz, K. R. Mitteilungen der Badenungsanstalt (Freiburg i. Br.) No. 21, 1970.
12. Saikku, O. Folia Forestalia, Institutum Forestale Fenniae No. 184, 1973, 15 p.
13. Grochowski, J. Sylwan 100(9):1-24(1956).
14. Korsun, F. Les (Bratislava) 2(1-2):51-4(1955).
15. Klem, G. S. Medd. Norske Skogforsoksvesen 27(1):96:63-90(1969).
16. Pechmann, H. Von; Wutz, A. Forstwiss. Cbl. 79(3/4):91-105(1960).
17. Nikolov, S.; Enchev, E. Nauchni Trudove, Vissh Lesotekhnicheski Institut, Sofiya 18:5-12(1971).
18. Dietz, L. P. Holz Roh- Werkstoff 33(4):135-41(1975).
19. Alexe, A. N. Editura Agro-Silvica, Bucharest, 1964, 326 p.
20. Colombo, P.; Corbetta, D.; Pirotta, A.; Ruffini, G. Ind. Carta (n.s.) 1(12):501-18(1963).
21. Corbetta, D. Ind. Carta (n.s.) 2(7):263-76(1964).
22. Croon, I. Pulp Paper Mag. Can. 66(2):T71-6(1965).

23. Sharkov, V. I.; Muromtseva, V. Lesokhim. Prom. 3(4):3-7(1940).

24. Larinkari, G. Thesis Abo Akademi, Finland (Helsingfors, Tilgmanns Tryckeri, 1947).

25. Aurell, R. Svensk Papperstidn. 66(23):978-89(1963).

26. Lindstedt, G.; Misiorny, A. Acta Chem. Scand. 5:121-8(1951).

27. Mirov, N. T. USDA, Forest Serv. Tech. Bull. No. 1239, 1961.

28. Semmler, F. W.; von Schiller, H. Ber. der deut. chem. Gesell. 60:1591-1607(1927).

29. Kolbe, M.; Westfelt, L. Acta Chem. Scand. 21(2):585-7(1967).

30. Assarsson, A.; Akerlund, G. Svensk Papperstidn. 69(16):517-25(1966).

31. Thielges, B. A. Phytochem. 7(8):1411-13(1968).

32. Donetzhuber, A.; Johansson, K.; Sandstroem, C. Appl. Polymer Sci. (Appl. Polymer Symp.) (28):889-901(1976).

33. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485, 1927, 101 p.

34. Aurell, A. R. Svensk Papperstidn. 69(21):736-45(1966).

35. Colombo, P.; Corbetta, D.; Pirotta, A.; Ruffini, G. Svensk Papperstidn. 67(12):505-11(1964).

36. Dillen, S.; Noreus, S. Svensk Papperstidn. 70(4):122-34(1967).

37. Farkos, J.; Jaros, J. Papir Celuloza 20(7):185-90(1965).

38. Gugnin, Yu. A. Bumazh. Prom. 6:3-4(1968).

39. Hartler, N. Paperi Puu 44(7):365-74(1962).

40. Jarvela, O.; Makkonen, H. Tappi 50(3):147-50(1967).

41. Mannbro, N. V. Pulp Paper Mag. Can. 62(2):T66-74(1961).

42. Hartler, N.; Stockman, L.; Sundberg, O. Svensk Papperstidn. 64(3):67-85(1961).

43. Marchlweska-Szrajerowa, J. Przeglad Papier 3:104-9(1947).

44. Hagglund, E. Paper Trade J. 85(21):41-4(1927).

45. Nowakowski, J. Przeglad Papier. 26(8):263-8(1970).

46. Ress, H. Zellstoff-Faser 32(7):97-106(1935).

47. Eliashberg, M. G.; Tsypkina, M. N. Bumazh. Prom. 34(12):2-6(1959).

48. Zhigirzhi, L. G.; Kudryavtseva, T. S. Nauchn. Tr. Tsentr. Nauchn.-Issled. Inst. Tssellyul. Bumazh. Prom. (43):82-92(1959).

49. Bitschnan, K.; Patt, R.; Sandermann, W. Papier 24(3):130-7(1970).

50. Hemingway, R. W.; Hillis, W. E. Appita 24(6):439-43(1971).

51. Hartler, N.; Olsson, L. A. Svensk Papperstidn. 75(13):559-65(1972).

52. Kleppe, P. J.; Kringstad, K. Norsk Skogind. 17(11):428-40(1963).

53. Aurell, R.; Hartler, N. Svensk Papperstidn. 70(4):113-21(1967).

54. Kinzner, K. Zellstoff Papier 18(9):271-6(1969).

55. Brecht, W.; Schroter, H.; Suttinger, R. Papier-Fabr. 36(40):413-17(1938).

56. Barker, E. F. Paper Trade J. 146(29):20-4(1962).

57. Ruhlemann, F. Zellstoff Papier 18(3):170(1938).

58. Schwabe, K. Wochbl. Papier-Fabr. 68(48):909-11(1937).

59. Bonness, H.; Philipp, B. Zellstoff Papier 14(8):225-9(1965).

60. Reed, R. Paper Technol. 8(3):253-6 et seq.(1967).

61. Packman, D. F. Paper Technol. 8(4):339-40(1967).

62. Brecht, W.; Schroter, H.; Suttinger, R. Papier-Fabr. 36(40):418-20(1938).

63. Dewhirst, L.; Rusten, D. Paper Technol. 8(3):258-63(1967).

64. Evans, J. C. W. Paper Trade J. 143(36):42-8(1959).

65. Lagergren, S.; Lunden, B. Pulp Paper Mag. Can. 60(11):T338-41(1959).

66. Virkola, N.-E.; Jarvela, O.; Vartiainen, V. Paper Trade J. 150(3):52-3(1966).

67. Chem. Technol. 490-3(Aug. 1974).

NORWAY SPRUCE

Scientific Name *Picea abies* (L.) Karst.

Synonyms *Picea excelsa* Link., European whitewood

Family Name Pinaceae

Range Native of Europe, except south and west portions. Planted in southeastern Canada and northeastern United States. It has escaped from cultivation in Connecticut and elsewhere but apparently is not naturalized.

Silvics The tree has a straight, slightly tapering bole, sometimes free from branches for a considerable distance from the base, a slender, pyramidal crown, and a shallow, widespreading root system. In Europe it grows in valleys and upon the mountain slopes. It prefers rather rich, moist soils and cannot endure very dry or very sterile soils. It is planted in pure stands or in mixture with other coniferous trees. This species is not as hardy to low temperatures as red spruce or white spruce, and also tends to die at the top when 60-70 years old. It is rated as rather tolerant.

Tree Dimensions 50-80 ft (15-24 m) tall and 18-24 inches (46-61 cm) in diameter.

Pathology

The most important root rots of Norway spruce are the shoestring root rot (*Armillariella mellea*) and the white stringy root rot (*Heterobasidion annosum*). Other rots include the stringy white trunk rot (*Ganoderma lucidum*), the red-brown butt rot (*Phaeolus schweinitzii*), and the conifer trunk rot (*Stereum sanguinolentum*). The fir and spruce leaf cast (*Lophodermium picea*) can cause early defoliation where attacks are severe. Two cankers of Norway spruce are the root crown canker (*Phytophthora cinnamomi*) and the conifer canker (*Valsa kunzei*).

Norway spruce in the U.S. and Canada is heavily attacked by the white pine weevil (*Pissodes strobi*) and it is second in host preference behind eastern white pine. Young trees are stunted and distorted, greatly reducing the quality and quantity of lumber produced (*1*). Defoliators of Norway spruce are the European spruce sawfly (*Diprion hercyniae*), the yellow-headed spruce sawfly (*Pikonema alaskensis*), and the red-headed pine sawfly (*Neodiprion lecontei*). Norway spruce is a preferred host for the eastern spruce gall aphid (*Adelges abietis*). This aphid is a serious pest where the aesthetic value of the tree is a consideration.

Gross Features of the Wood Similar to red spruce.

Microscopic Structure of the Wood

Tracheids. Average, 3.5 mm (1.7-3.7 mm) in length and 27 μm in width. Wall thickness of earlywood tracheids, 2-4 μm, of latewood tracheids, 4-8 μm. Eskilsson (*2*) found an average fiber width of 46.3 μm. According to Nesterov and Stepanov (*3*), the effect of age was most marked on cell wall thickness, while growth class and devt. class affected the diameter of springwood more. Stairs, *et al.* (*4*) found a fiber length of 3.22 mm for slow-growth trees *vs.* 3.48 mm for fast-growth trees.

Additional publications in this area include Denne and Wilson (*5*), Dietz (*6*), Hakkila (*7*), and Marton, *et al.* (*8*).

Gross Features of the Bark On old trunks roughened with large, rather thick, reddish-brown scales; on younger trunks the scales are thinner and closer; volume about 10%. Holmsgaard and Jakobsen (*9*) found that bark thickness increases with decreasing site quality class. Thinning has very little effect on bark thickness.

Microscopic Structure of the Bark

Eremin (*10*) studied the structural features of various forms of bark, including scaly, smooth, longitudinally cracked, and plated.

Physical Properties of Wood

Specific gravity	Green volume	0.37
	Oven-dry volume	0.43
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	23 (368)

Worrall (*11*) found that 42% of the variation in wood specific gravity associated with phenological variables. A strong relationship between wood specific gravity and earlywood specific gravity was shown.

According to Stairs, *et al.* (*4*), specific gravity of 32-year-old trees growing in New York ranged from a mean of 0.319 for slow-growing trees to 0.324 for the fast-growing groups.

Mergen, *et al.* (*12*) found a highly significant relationship between specific gravity and latewood percent.

Wood density decreased 2-7% after treatment with N, P, K, Ca fertilizer (*13*). However, volume and dry matter production were more than doubled.

Denne (*14*) suggested, theoretically, that high density wood could be produced by selecting seedlings with relatively slow rates of shoot elongation.

Percent shrinkage, dried to 0% moisture content: r – 3.6, t – 7.8, v – 12.0.

Physical Properties of Bark

Bark specific gravity was unaffected by log diameter (*15*).

Moisture content increased with decreasing bark thickness from the stem base to the top, and average values varied during the year from 103.1% to 134.8% (mean, 124.5%) (*16*).

Chemical Composition of Wood

Proximate Analyses

	Jayme and Hahn (*17*)	Aurell (*18*)
Lignin, %	28.2 (Halse)	26.9
Holocellulose, %		70.3
Yield on wood, %	76.2	
Lignin residue, %	3.1	
Ash, %	0.3	
MeOH-benzene extr., %	0.2	
Pentosans, % (corr.)	14.3	
Cellulose, % (*a*)		42.3
Hemicellulose (alkali extraction of wood)	12.1	
Ash, %	0.4	0.31
Methanol-benzene, %	0.9	
Pentosans, %	11.0[a]	
Xylan, %		8.7
Glucomannan, %		17.4
Galactan, %		1.8
Araban, %		0.0
Alcohol extractives, %		1.8
Alkaline extraction of Holocellulose		
Yield on holocellulose, %	14.9	
Yield on wood, %	11.4	

[a](Corr. for uronides).

	Schwalbe and Ender (*19*)		Stairs, *et al.* (*4*) (32-yr-old trees)	
	Middle-aged	Old	Fast growth	Slow growth
Lignin, % (Klason)	26.70	27.11	28.2	28.0
Cellulose (Kurschner), %	52.37	52.47		
Ash, %	0.30	0.28		
Pentosans, %	12.69	12.92	13.0	12.2
Resin, fat, wax, %	0.72	1.50		
Solubility in				
Alcohol-benzene, %			0.90	2.05
Hot water, %			1.00	0.46

Wood from various Rumanian provenances contains 48-53% Kurschner-Hoffer cellulose, 44-47% alpha-cellulose, 26.5-29.5% lignin, 7.3-8.6% pentosans, 10.0-11.6% 1% NaOH solubles, 1.0-2.0% alcohol-benzene solubles, and 0.16-0.30% ash (*20*). Extracted wood contains 27% Klason lignin, 41% alpha-cellulose, 20% glucomannan, 10% xylan, and 2% galactan (*21*). Lignin content, as determined by means of hydrogen fluoride, amounts to 27.5-32.1% (*22*). Poller (*23*) compared the chemical composition of the wood from trees in three different stands of the same age and class: ether extractives, 0.90-1.07%; ash, 0.24-0.26%; cellulose, 52.5-54.9%; lignin, 27.9-29.2%; pentosan, 11.3-11.8%. The ash contains 27.6-38.5% CaO, 8.94-10.70% K_2O, and 2.91-3.25% Na_2O.

Extractives

Pensar (*24*) studied the distribution and composition of the ether extractives of earlywood and latewood of cross sections in two Finnish trees.

Wood contained 0.93-1.15% dichloromethane extractives; trees felled in autumn had the greatest content (*25*). Hydroxymatairesinol, matairesinol, liovil, and conidendrin were identified in sound heartwood (*26*).

Swan (*27*) analyzed fifty 65-year-old trees throughout the year and reported an average of 1.6% acetone extractives, 0.25% unsaponifiables, 0.05% free fatty acids, 0.22% resin acids, and 0.35% combined fatty acids. The lowest resin content occurred in sulfite pulps from green wood cut in early summer.

The influence of log storage on various extractives was studied by Malevskaya, *et al.* (*28*). Freshly cut wood gave 2.03% ether, 1.70% petroleum ether, 2.14% dichloromethane, and 2.57% acetone solubles; 6-month summer-stored wood gave 1.57% ether, 0.81% petroleum ether, 1.63% dichloromethane, and 2.46% acetone solubles. Percentages are tabulated for total acids, resin acids, fatty acids, total neutral, unsaponifiable fraction and saponifiable fraction in all categories.

Other Information

For information on volatile substances, mainly hydrocarbons, see Donetzhuber, *et al.* (*29*).

Pulping

Kraft. The wood is readily reduced and the pulp is strong and of fine texture (*30,35*).

Mechanical. The wood is readily reduced, and the pulp is of excellent color and standard strength; power required is comparable to that for white spruce (*30,36-40*).

Sulfite. The wood is readily reduced, and the pulp is strong and of fine texture and excellent color; it is easily bleached to excellent white (*30,41-45*).

High yield kraft. High-yield pulps of good quality are obtained from chips of small and uniform size and by maximum penetration of liquor into the wood, which is achieved by deaeration and preliminary impregnation. Sprucewood is preferred over pine for the process because it is more easily cooked and contains less lignin and undercooked chips at equal yields (*46*). Poppel *et al.* (*47*) found that satisfactory strength properties were obtained with relative savings in total energy consumption.

High yield polysulfide. Kleppe and Vethe (*48*) found the high-yield polysulfide process to be superior to kraft, in that it permitted considerable power savings in defibration and refining of pulps. It was also superior in tensile strength, elongation, and especially stiffness.

Cold soda. Strength properties are constant for chip thicknesses up to 5 mm; a moderate drop in strength was apparent with thicker chips (*49*). Pulp produced by this process was suitable for paper manufacture (*50*).

Refiner groundwood. See Bonness and Philipp (*51*).

Chemigroundwood. According to Brecht and Weiss (*52*), sodium carbonate improves production and reduces power consumption but lowers strength and brightness; sodium sulfite improves brightness and breaking length. Dahm (*53*) found that, by postsulfonation of groundwood at a pH of 8.5, tensile strength increases were obtained without serious loss of opacity and with some reduction in brightness and freeness.

Asplund defibrator. Dahm, *et al.* (*54*) pulped wood at 27.5% and 40.3% moisture content. Pulp produced from the higher moisture content wood was significantly superior in quality, leading to the conclusion that seasoned wood should be treated differently than green wood for optimum properties.

Magnesium bisulfite. Although the breaking length is slightly lower than that from Ca-base acid sulfite pulp, all other strength characteristics compared favorably with it. Suitable for folding boxboard and magazine papers (*58*).

Jayme, *et al.* (*55*) obtained best results with magnefite pulping with an impregnation period of 5 minutes, heat-up time of 45 minutes to maximum temperature (180°), and short digestion (8-14 minutes). The process is economical, especially for continuous processes, owing to low steam consumption, high yield and exceptionally good strength properties. According to Ogawa and Gorbatsevich (*56*), in the vapor-phase magnefite pulping, as the concentration of cooking liquor increased, cooking time needed to reach a certain yield decreased. Pentosan contents of pulps cooked under various conditions did not differ, and more hemicellulose was retained in pulp cooked at higher chemical concentrations.

NSSC. Marton and Bhargava (*57*) found that neutral sulfite pulping did not produce an acceptable pulp. In addition, when the pH of the liquor dropped below 7, there was a tendency for lignin to be readsorbed onto the fiber. Marton and Zank (*49*) found strength properties showed distinct maxima at chip thicknesses of 5 mm in sulfite processes.

Literature Cited

1. Hastings, A. R.; Godwin, P. A. USDA, Forest Service, Forest Pest Leaflet No. 21, 1970, 7 p.
2. Eskilsson, S. Svensk Papperstidn. 75(10):397-402(1972).
3. Nesterov, V. G.; Stepanov, R. S. Doklady TSKhA (Dokl., Mosk. Sel'skokhoz Akad.) 19:257-61(1966).
4. Stairs, G. R.; Marton, R.; Rizzio, M.; Brown, A. F. Paper presented at the Third Forest Biology Conference, TAPPI, Madison, WI, Nov. 2, 1965.
5. Denne, M. P.; Wilson, J. E. Planta 134(3):223-8(1977).
6. Dietz, P. Holz Roh- Werkstoff 33(4):135-41(1975).
7. Hakkila, P. Commun. Inst. Forest Fenniae 61(5), 98 p. 1966.
8. Marton, R.; Rushton, P.; Sacco, J. S.; Sumiya, K. Tappi 55(10):1499-1504(1972).
9. Holmsgaard, E.; Jakobsen, B. Forstl. Forsgsv. Danm. 32(3):265-94(1970).
10. Eremin, V. M. Izv. VUZ, Lesnoi Zh. 20(5):5-10(1977).
11. Worrall, J. Tappi 53(1):58-63(1970).
12. Mergen, F.; Burley, J; Yeatman, C. W. Tappi 47(8):499-504(1964).
13. Seibt, G. Aus dem Walde, Hannover No. 6:51-82(1963).
14. Denne, M. P. Forestry 46(2):117-24(1973).
15. Carre, J. *In* Rappart d'Activite, 1972, Station de Technologie Forestiere, Gembloux (1973) 6-41.
16. Nikolov, S.; Enchev, E. Nauchni Trudove, Vissh. Lesotekhnicheski Institut, Sofiya 18:5-12(1971).
17. Jayme, G.; Hahn, G. Holzforsch. 14(2):52-6(1960).
18. Aurell, A. R. Svensk Papperstidn. 69(21):736-45(1966).
19. Schwalbe, C. G.; Ender, W. Cellulosechem. 17(3/4):36-40(1936); 17(5/6):54-6(1936).
20. Burova, T.; Tocan, M. Celuloza Hirtie 10(7/8):231-5(1961); 11(4):91-9(1962).
21. Croon, I. Pulp Paper Mag. Can. 66(2):T71-6(1965).
22. Klatt, W. Angew. Chem. 48(6):112-14(1935).
23. Poller, S. Zellstoff Papier 16(10):322-7(1967).
24. Pensar, G. Acta Acad. Aboensis Math. Phys. 27B(5):1-31(1967).
25. Pensar, G. Acta Acad. Aboensis Math. Phys. 29B(3):1-4(1969).
26. Shain, L.; Hillis, W. E. Phytopathology 61(7):841-5(1971).
27. Swan, B. Svensk Papperstidn. 71(11):436-40(1968).
28. Malevskaya, S. S.; Karmankhova, V. D.; Kharad, S. D. Bumazh. Prom. 30(9):14-15(1955).
29. Donetzhuber, A.; Johansson, K.; Sandstroem, C. J. Appl. Polymer Sci. (Appli. Polymer Symp.) (28):889-901(1976).

30. Wells, S. D.; Rue, J. D. USDA, Dept. Bull. No. 1485, 1927, 101 p.

31. Aurell, R.; Hartler, N. Svensk Papperstidn. 68(3):59-68(1965).

32. Farkas, J. Sb. Vyskum. Prac Odboru Celulozy Papiera 6:177-96(1961).

33. Hagglund, E.; Aarsrud, K. Svensk Papperstidn. 36(23):807-9(1933).

34. Hartler, N.; Stockman, L.; Sundberg, O. Svensk Papperstidn. 64(3):67-85(1961).

35. Iwanow, I.; Marker, B. Zellstoff Papier 7(6):167-76(1958).

36. Blechschmidt, J. Zellstoff Papier 19(9):268-75(1970).

37. Brecht, W.; Schroter, H.; Suttinger, R. Papier-Fabr. 36(41):421-2(1938).

38. Gajdos, J. Sb. Vyskum. Prac Odboru Celulozy Papiera 3:36-56(1958).

39. Jensen, W.; Nordman, L.; von Alfthan, G.; Paroneu, J. Paperi Puu 39(9):405-8, 410, 412-16(1957).

40. Laskeev, P. Kh. Bumazh. Prom. 4:20-1(1970).

41. Nippe, W. Papier 16(7):302-9(1962).

42. Ogait, A. Papier 7(23/24):471-8(1953).

43. Rozenberger, N. A. Bumazh. Prom. 31(6):6-10(1956).

44. Slavik, I. Zellstoff Papier 6(11):331-6(1957).

45. Vethe, A.; Loras, V.; Loschbrandt, F. Norsk Skogind. 14(5):167-78(1960).

46. Farkas, J. Papir Celuloza 18(7):137-40(1963).

47. Poppel, E.; Diaconescu, V.; Simionescu, C. Zellstoff Papier 10(3):84-90(1961).

48. Kleppe, P. J.; Vethe, A. Norsk Skogind. 20(7):249-50, 252-3, 255-6(1966).

49. Marton, R.; Zank, T. J. Invest. Tec. Papel 3(8):313-48(1966).

50. Routala, O.; Murto, J. D. Finnish Paper Timber J. 15(1):20-2(1933).

51. Bonness, H.; Philipp, B. Zellstoff Papier 14(8):225-9(1965).

52. Brecht, W.; Weiss, H. Papier 11(5/6):82-9(1957).

53. Dahm, H. P. Paperi Puu 48(10):591-4(1966).

54. Dahm, H. P.; Brandal, J.; Helge, K. Paperi Puu 40(7):355-8, 360(1958).

55. Jayme, G.; Broschinski, L; Matzke, W. Papier 18(7):308-14(1964).

56. Ogawa, E.; Gorbatsevich, S. N. Tappi 51(4):171-5(1968).

57. Marton, R.; Bhargava, D. P. Indian Pulp Paper 19(2):145, 147, 149-50, 152, 154, 156-8(1964).

58. Rowlandson, G. Tappi 55(6):959-64(1972).

EUROPEAN LARCH

Scientific Name *Larix decidua* Mill.

Family Name Pinaceae

Range A native of Europe, European larch is planted in southern Canada, northeastern United States and the Midwest. It has become established and naturalized locally in Connecticut, New York, and elsewhere.

Silvics European larch is an important species in its native habitat. This medium-sized to large tree possesses a deep root system and a long, spirelike crown. When forest grown, the bole is very straight and clean and the crown greatly reduced in size. Early height growth is related to depth of free rooting material and is inversely related to elevation (*1*). The species grows well on calcareous soils with pH values up to 7.8 but it is sensitive to poor surface drainage and soil compaction. However, it can tolerate a considerable range of soil texture and moisture. According to Aird and Stone (*2*), the mean site index at age 25 in New York and southern New England was 47.0 ft (14.3 m). The species hybridizes readily and hybrids between *L. decidua* and *L. leptolepis* (Japanese larch) exhibit superior growth. European larch is moderately sensitive to late spring frosts, with one study showing 4-17% severely damaged and 2-11% moderately damaged (*3*). Reproduction is entirely by seed and the species is intolerant, demanding about the same amount of light as aspen and locust.

Tree Dimensions 100-110 ft (30-34 m) tall and 16-20 inches (41-51 cm) in diameter.

Pathology

Larch is susceptible to several cankers, including the conifer canker (*Valsa kunzei*) and the larch canker (*Dasyscypha wilkommii*). The latter was found on European larch in two localities in the Northeast. Diseased trees were removed and, hopefully, the canker has been eliminated. There is recent evidence that larch is attacked but is moderately resistant to the European strain of scleroderris canker (*Scleroderris lagerbergii*). A common needle rust is *Melampsora paradoxa* (*M. bigelowii*). Damage, however, is rarely severe enough to affect growth. Rots affecting European larch include the pocket rot (*Phellinus pini*) and the red heart rot (*Stereum sanguinolentum*).

A major insect enemy of European larch is the larch sawfly (*Pristiphora erichsonii*), with the strain of European larch from the western Alps showing the greatest degree of resistance (*4*). The larch casebearer (*Coleophora laricella*) is another defoliator, with mortality occurring after several years of complete defoliation. The gypsy moth (*Porthetria dispar*) will also attack European larch, especially when it is growing near highly favored hardwoods.

Gross Features of the Wood The sapwood is yellowish to reddish-white and the heartwood is red-brown to red. The latewood zone is sharply delineated and conspicuous to the unaided eye, which makes the growth ring quite distinct. The transition from earlywood to latewood is abrupt. In the x-section the rays are very fine, not distinct to the unaided eye, and form a fine, close, inconspicuous fleck on the radial surface. Both longitudinal and horizontal resin canals are present. The longitudinal canals are small, inconspicuous, not visible to the unaided eye or appearing as whitish or dark flecks, sparse, confined mostly to the latewood, solitary or 2 to several contiguous tangentially. The smaller horizontal canals appear, with a hand lens, as somewhat broader, whitish rays spaced irregularly on the x-section and are invisible or barely visible with a hand lens on the tangential surface. Longitudinal parenchyma cells are not visible.

Microscopic Structure of the Wood

Tracheids. Longitudinal, 3.6 mm (2.3-4.3 mm) in length and 46.0 μm in width. Those in the latewood occasionally have spiral thickening. Bordered pits in 1-2 rows on the radial walls; tangential pitting present in the last few rows of latewood tracheids; pits leading to ray parenchyma small, quite uniform in size, with distinct border (piceoid). Volume occupied, approximately 91%. Liang (*5*) found that tracheid length was related at a highly significant level to growth percent.

Resin Canals. Thick-walled epithelial cells and occasional tylosoids present. Volume occupied, <1%.

Rays. Two types, uniseriate or rarely in part biseriate, and fusiform. The uniseriate rays are numerous (about 30 per sq mm on tangential surface) and 1-13+ cells in height. Ray tracheids are present in all types of rays, marginal and rarely interspersed, nondentate inner walls; marginal, usually in one row. Volume occupied, approximately 9%.

Longitudinal Parenchyma. Terminal and very sparse, or absent. Volume occupied approximately 1%.

Gross Features of the Bark Grayish, outside of scales carmine red; volume, 16-22%. Up to 30 years of age, little difference has been found in bark thickness (*6*).

Microscopic Structure of the Bark

Wattendorff (7) discusses the ultrastructure and development of the suberized calcium oxalate crystal cells in the bark.

Physical Properties of Wood

Specific gravity	Green volume	0.49
	Oven-dry volume	0.55
Density, lb/cu ft (kg/cu m)	Green	45 (721)
	Air-dry	37 (593)
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	29.5 (473)

Percent shrinkage, dried to 0% moisture content: r – 3.3, t – 7.8, v – 11.8.

Physical Properties of Bark

Specific gravity oven-dry weight & volume (*8*)	0.35

Chemical Composition of Wood

Proximate Analyses

	Curran *et al.* from New Zealand plantation (*9*)
Lignin, %	30.5
C. & B. cellulose, %	55.4
Alpha-cellulose, %	38.2
Total pentosans, %	12.1
Pentosans in cellulose, %	4.7
Solubility in	
Ether, %	1.1
Alcohol-benzene, %	2.5
1% NaOH, %	16.7

The chemical composition of the wood and the distribution along the tree trunk of chemical constituents (cellulose, pentosans, lignin, ether and hot-water extractives, polyuronic acids, reducing substances, methoxyl groups, and ash) are tabulated for trees from the Ural mountains (*10*).

Extractives. One can obtain high-quality oleoresin from "resin pockets" of the tree by boring deep into the trunk at its base; water solubles, 10.6-25.3%; alcohol-benzene solubles, 2.2-5.0%; and ether solubles, 0.62-1.6% (*11*). Arabinogalactan content of 26-year-old trees ranged from 4.2-5.9% (*12*); there was little or none in the sapwood. Boweng (*13,14*) found 3.4% arabinogalactan, based on acetone-extracted, air-dried heartwood. Orman (*15*) found the arabinogalactan content to decrease with increasing height in the tree up to the green crown level. The constitution of arabinogalactan has been studied in detail (*16,17*). Dihydroquercitin (taxifolin) and dihydrokampferol (aromadendrin) constituted 70% of the ether extractives, with liovil and *seco-iso*-lariciresinol also present (*18*). The heartwood extractives (MeOH and seq. H_2O) were greatest in the lower portion of the tree (6-8%), whereas sapwood extractives varied little with height in the tree (*19*). MeOH solubles included taxifolin and aromadendrin, and water solubles contained arabinogalactan (*19*). For information on sinapyl and related aldehydes, see Gibbard and Schoental (*20*).

Chemical Composition of the Bark

Extractives. Powdered bark (4.2 kg) was extracted with CH_2Cl_2 (*21*). The extract (231 g) was divided into light petroleum solubles (167 g) and insoluble (64 g) parts. A portion (47 g) of the petroleum-soluble part was separated into neutral (22.6 g) and acidic (24.4 g) fractions. Part of the neutral fraction was chromatographed, and increasing concentrations of ether eluted the following compounds: alkanes (1.0% of neutral fraction), terpenoid hydrocarbons (1.7%), triglycerides (22.0%), fatty alcohols (4.7%), sitosterol (5%), 13-epimanool (11.4%), terpenoid alcohols (6.7%), torulosyl acetate (11.6%), torulosal (2.8%), torulosol (6.7%). The rest (14.7%) was mainly a complex mixture of oxygen-containing compounds.

Pulping

Kraft. The yield is nearly normal; alkali consumption is high; tensile strength is adequate; bursting strength is reduced, and tear strength is high (*22-25*).

Sulfite. Yields are nearly normal, particularly from sapwood, and pulps are nearly as strong as those from spruce (*22*).

Soda. This process is not suitable for European larch (*22*).

Bisulfite. The pulp has good tensile strength, low tear strength, and can be bleached to a 90% brightness (*26-29*).

Mechanical. Larch gave lower yields than spruce and had better strength properties than pine. The chief drawback was the poor color, poorer than all other species tested (pine, poplar, beech and horse chestnut) (*30*). Blechschmidt (*31*) found larch second to spruce in groundwood quality and better than poplar, beech and birch (in that order); brightness was again low.

Steamed groundwood. Power consumption was less and the yield higher than for the regular groundwood process; strength properties were considerably better, while whiteness was very poor (*32*).

Stora-Brite. Although the wood can be pulped by this process, the yield, wetness, tear strength, and opacity are lower than for spruce, pine or Douglas-fir. Although unbleached brightness is low, pulps can be bleached to a brightness of 91-94 (Elrepho) (*33*).

Sivola (*2-stage*). High purity pulps can be prepared, particularly from the sapwood, which is higher in cellulose and lower in extractives than heartwood. Arabinogalactan is completely removed from the pulps. Mechanical properties are generally good, compared to similar sprucewood pulps; tear strength is particularly high (*34*).

NSSC. See Maliskin and Korotkov (*35*) and Riese (*36*).

Literature Cited

1. Day, W. R. Forestry 20:7-20(1946).
2. Aird, P. L.; Stone, E. L. J. Forestry 53:425-9(1955).
3. Stoeckeler, J. Am. Christmas Tree Growers' J. May 1965, p. 36-40.
4. Genys, J. B.; Harman, D. M. J. Economic Entomology 69(5):573-8(1976).
5. Liang, S. C. Forestry 22:222-37(1948).
6. Yanagisawa, T.; Kawanishi, T. Bull. For. Expt. Sta. Meguro, Tokyo 79:125-44(1955).
7. Wattendorff, J. Z. Pflanzenphysiol. 60(4):307-47(1969).
8. Harkin, J. M.; Rowe, J. W. USDA, Forest Serv. Res. Note FPL-091, 1969, 41 p.
9. Curran, C. E.; Baird, P. K.; Schafer, E. R.; Monsson, W. H.; Chidester, G. H.; Entrican, A. R. N.Z. State Forest Serv., Branch of Forest Prod., Bull. No. 6, 1928, 100 p.
10. Burde, N. R.; Kozlov, V. N. Izvest. Vysshikh Ucheb. Zaved., Lesnoi Zh. 3(4):134-40(1960).
11. Bobrov, A. I.; Mutovina, M. G. Tr. Tsentr. N11 Bumagi No. 3:48-64(1968).
12. Cote, W. A., Jr.; Day, A. C.; Simson, B. W.; Timell, T. E. Holzforsch. 20(6):178-92(1966).
13. Boweng, H. O. Acta Chem. Scand. 13(9):1869-76(1959).
14. Boweng, H. O. Svensk Kem. Tidskr. 73(3):115-30(1961).
15. Orman, H. R. Report of Forest Res. Inst., N.Z. Forest Serv. 1963 (1964), 79 p.
16. Aspinall, G. O.; Hirst, E. L.; Ramstad, E. J. Chem. Soc. 1958:593-601(1958).
17. Roudier, A. ATIP Bull. 16(5):343-55(1962).
18. Freudenberg, K.; Weinges, K. Tetrahedron Letters No. 17:19-22(1959).
19. Uprichard, J. M. Holzforsch. 17(5):129-34(1963).
20. Gibbard, S.; Schoental, R. J. Chromat. 44(2):396-8(1969).
21. Norin, T.; Winnell, B. Phytochem. 13(7):1290-2(1974).
22. Cook, D. B. J. Forestry 45(10):763-4(1947).
23. Uprichard, J. M.; Gray, J. T. Appita 27(3):185-91(1973).
24. Hakkila, P.; Winter, A. Communicationes Inst. Forestalis Fenniae, Helsinki, 1973, 45 p.
25. Melms, F.; Muhlberg, L.; Zirngibl, E. Zellstoff Papier 18:15-22(1969).

26. Philipp, B.; Jacopian, V.; Casperson, G. Faserforsch. Textiltech. 21(4):153-63(1970).

27. Patt, R.; Troger, F. K.; Czirnich, W. Das Papier 28(1):1-6(1974).

28. Il, B. S.; Simionescu, C. I. Cellulose Chem.. Technol. 10(4):441-52(1976).

29. Bobrov, A. I.; Mutovina, M. G.; Bondareva, T. A. Cellulose Chem. Technol. 6(5):559-69(1972).

30. Brecht, W.; Schroter, H.; Suttinger, R. Papier-Fabr. 36(40):413-17(1938).

31. Blechschmidt, J. Zellstoff Papier 19(9):268-75(1970).

32. Brecht, W.; Schroter, H.; Suttinger, R. Papier-Fabr. 36(40):418-20(1938).

33. Dewhirst, L.; Rusten, D. Paper Technol. 8(3):258-63(1967).

34. Jacopian, V. Zellstoff Papier 14(3):65-73(1965).

35. Maliskin, K. N.; Korotkov, V. S. Celuloza Hirtie 6(8):272-7(1957).

36. Riese, W. Zellstoff Papier 11(6):216-22(1962).

JAPANESE LARCH

Scientific Name *Larix leptolepis* (Sieb. & Zucc.) Gord.

Synonyms Karamatsu (Japanese common name)

Family Name Pinaceae

Range Japanese larch has a small natural range, 77 square miles (200 square km), at elevations of 2950-9000 ft (900-2800 m). The soils are of volcanic or limestone origin, rainfall ranges from 50-140 inches (127-356 cm) per year, with a mean annual temperature of 34-45° (*1*). In the United States, the species has been successfully planted from the Northeast to the Great Lakes Region and Iowa.

Silvics A medium to large-sized tree, Japanese larch possesses a deep root system and a long, spirelike crown. It is generally superior to European larch in height growth and total volume. Japanese larch hybridizes readily, and hybrids with *L. decidua* (European larch) exhibit increased growth. In a trial in Japan, it was concluded that 300 trees/ha were suitable densities ten years after planting, considering growth rate and the useful pulpwood production from the first thinning (*1*). The species is rated as intolerant.

Pathology

Japanese larch is susceptible to several cankers, including the conifer bark canker (*Dasyscypha ellisiana*) and the larch canker (*Dasyscypha willkommii*). The latter disease was found in two localities in the Northeast. Diseased trees were removed and, hopefully, the canker has been eliminated. Japanese larch appears to be less susceptible to this canker than European larch. The root crown canker (*Phytophthora cinnamomi*) also attacks Japanese larch. A root rot especially prevalent in nurseries under highly humid conditions is *Cylindrocladium scoparium*.

A major insect enemy of Japanese larch is the larch sawfly (*Pristiphora erichsonii*). Marked loss of radial increment occurs after 4-6 years of outbreak, and after 6-9 years of moderate to heavy defoliation, tree mortality occurs (*2*). Genys and Harman (*3*) found that Japanese larch was more susceptible to sawfly attack than European larch. The larch casebearer (*Coleophora laricella*) is another defoliator, with mortality occurring after several years of complete defoliation. The larch woolly aphid (*Adelges strobilobius*) can be recognized by the white woolly masses that appear on the needles and the clusters of aphids at the base of needles.

Gross Features of the Wood Similar to European larch. Greguss (*4*) found that Japanese larch wood is generally low in percent latewood. Hakkila and Winter (*5*) found the percentage of heartwood (58%) was higher in Japanese larch than in other larch species.

Microscopic Structure of the Wood

Tracheids. Average, 3.6 mm in length. An average tracheid length of 2.07 mm has been reported for 12-year-old trees in Michigan (*6*). Liang (*7*) found that tracheid length was related at a highly significant level to growth percent. Mikami and Nagasaka (*8*) discuss selection of Japanese larch for minimizing spiral grain.

Gross Features of the Bark The bark scales off in narrow strips, leaving red scars. Up to 30 years of age, little difference has been found in bark thickness (*9*). Hakkila, *et al.* (*10*) reported the bark percentage in mature Japanese larch averaged 12.3% (weight basis).

Physical Properties of Wood

Specific gravity	Green volume	0.48
Density, lb/cu ft (kg/cu m)	Oven-dry weight per green volume	28 (448)

Lee (*6*) found an average specific gravity of 0.398 for 12-year-old trees in Michigan.

According to Langner and Reck (*11*), wood density decreased with increasing volume increment. This decrease was more pronounced in Japanese larch than in European larch or their hybrid.

Seibt (*12*) also found that the basic density of the wood was reduced by 2-7% through the application of fertilizer. Volume and dry-matter production were more than doubled however.

Chemical Composition of Wood

Carbohydrates. The wood contains arabinogalactan and up to 30% of galactan (*13*). Fractionation of hemicellulose yielded a galactoglucomannan and two further fractions consisting of mixtures of galactoglucommanan, xylan and galactan (*14*). For additional information see Nikitin, *et al.* (*15*).

Extractives. See Nikitin, *et al.* (*15*). Packman (*16*) reported that extractives from mature wood (age 15-24) amounted to 7.7%. Juvenile larch wood is lower in extractives because it consists mostly of sapwood (*10,17*).

Other Information. The heartwood contains flavone phenols which impart appreciable microbial resistance (*13*). Flavonoid content increases gradually inwards through the sapwood, rises considerably at the sapwood/heartwood boundary, and decreases slowly to the pith (*18*).

Pulping

Acid sulfite. Flavone phenols in the heartwood interfere with digestion (*13*).

Bisulfite. This process is not so good as kraft or two-stage sulfite pulping (*13*).

Calcium-base sulfite. It is difficult to cook larchwood by this process, and the pulp is yellow because of the flavanones in the heartwood (*19*).

Kraft. The wood is entirely suitable for kraft pulp (*13*) and kraft paper (*20*). Chips extracted at 100°C for 4 hr. were subjected to aqueous prehydrolysis at 150°C and then cooked by the kraft process with a liquor containing 18.9% alkali (as Na oxide) and having a sulfidity of 26.2%. The unbleached pulp was free of undercook, contained 95.6% alpha-cellulose, 3.7% pentosans, and had a D.P. of 840 and a cuam viscosity of 146 mp at a concentration of 0.7% (*15*). It can also be pulped by the prehydrolysis kraft process (*21*).

Sodium hydroxide-bisulfite. This process can be used (*21*).

Two-stage sodium bisulfite/sodium carbonate + sodium sulfite (*Sivola*). This process can be used (*21*).

Two-stage sodium bisulfite (*Stora*). Pulp from a 56-year-old tree was difficult to bleach and showed a marked tendency to brightness reversion, whereas pulp from assorted small thinnings was readily bleached to high brightness; for yield and strength properties of pulps, see Packman (*16*).

Two-stage sulfite. This process gives pulps with high brightness without yellowing, resulting in a very low permanganate number and a low content of ether extractives; the pulp is easy to refine to give good strength properties (*19*). See also Nevalainen and Hosia (*13*).

Other Information. Finnish larch pulps made by the acid sulfite, two-stage sulfite, kraft, and bisulfite process are similar to U.S. southern kraft pulps; the slightly lower yield is more than offset by the lower wood consumption. The heartwood, which contains flavone phenols, aggravates chemical digestion, especially in acid sulfite pulping (*13*). The wood can be pulped by the Arbiso, Magnefite, Sivola, Stora, Krafors, and Weyerhaeuser processes, which also give yellow pulps (*19*). For information on chemical pulping see Mottet (*22*). Pulps made by the sodium bisulfite, two-stage sodium bisulfite/sodium carbonate + sodium sulfite, prehydrolysis kraft, or sodium hydroxide-bisulfite processes have high purity and good chemical reactivity, especially those from sapwood, which has a higher amount of cellulose and much lower amount of extractives than heartwood. In the Sivola and prehydrolysis kraft processes the arabinogalactan is completely removed from the pulps. The mechanical strength properties of the larchwood pulps are generally good compared to those of similar sprucewood pulps. In particular, the tear strength is very high, rendering the pulps well suited to the manufacture of bag papers (*21*).

Literature Cited

1. Sakamoto, T. Ten year growth at different spacing of *Larix leptolepis* and other 7 species. Oji Institute for Forest Tree Improvement Tech. Note No. 77, 1969.
2. Baker, W. L. USDA, Forest Serv. Misc. Publ. No. 1175, 1972, 642 p.
3. Genys, J. B.; Harman, D. M. J. Econ. Entomology 69(5):573-8(1976).
4. Greguss, P. Akademiai Kiado, Budapest, 1955, p. 114.
5. Hakkila, P.; Winter, A. Communicationes Instituti Forestalis Fenniae, Helsinki, 1973, 45 p.
6. Lee, C. H. USDA, Forest Serv., Gen. Tech. Rept. No. NC-26, 1976, p.35-46.
7. Liang, S. C. Forestry 22:222-37(1948).
8. Mikami, S.; Nagasaka, K. Bull. Gov. Forest Expt. Sta., Tokyo, Japan, No. 276:1-22(1975).
9. Yanagisawa, T.; Kawanishi, T. Bull. Forest Expt. Sta. Meguro, Tokyo No. 79:125-44(1955).

10. Hakkila, P.; Nikki, M.; Palenius, I. Paperi Puu 54:41-58(1972).

11. Langner, W.; Reck, S. Holzforsch. 20(6):194-9(1966).

12. Seibt, G. Aus dem Walde, Hannover No. 6:51-82(1963).

13. Nevalainen, K.; Hosia, M. Paperi Puu 51(5):433-8, (6):503-10(May-June 1969).

14. Hashi, M.; Teratani, F.; Miyazaki, K. J. Jap. Wood Res. Soc. 16(1):37-41(1970).

15. Nikitin, N. I.; Antonovskii, S. D.; Zaitseva, AF.; Belozerova, L. A.; Abakyan, N. D. Bumazh. Prom. (8):3-5(Aug. 1970).

16. Packman, D. F. Holzforsch. 20(4):110-13(Aug. 1966).

17. Uprichard, J. M. Holzforsch. 17:129-34(1963).

18. Sasaya, T.; Demachi, S.; Terazawa, M. Res. Bull. Expt. For. Hokkaido Univ. 27(2):429-43(1970).

19. Aida, K.; Kikuchi, A. J. Jap. Tappi 18(4):169-82(April 1964).

20. Mottet, A.; Quoilin, J. Inst. Agron. Sta. Recherches Gembloux, Bull. 25:116-138(1957).

21. Jacopian, V. Zellstoff Papier 14(3):65-73(March 1965).

22. Mottet, A. Rapp. Sta. Tech. For., Gembloux 1968, 1969, p. 5-39.

WORD LIST*

Cambium. A cylinder, strip, or layer of meristematic cells which divide to give cells that ultimately form a permanent tissue. The cambium in the stem and root gives rise to xylem and phloem.

Cell. A nucleus with the cytoplasm with which it is in intimate contact; in plants it is usually bounded by a definite cell wall.

Cellulose. A condensation product of a various number of glucose units, giving a fibrous structure. The main constituent of plant cell walls.

Cortex. The tissue in a stem or root between the vascular bundles and the epidermis. Typically, it is parenchyma.

Dbh. Diameter breast height (4.5 feet).

Deciduous. The seasonal shedding of leaves.

Family. The taxonomic division between an order and a genus; it may be a subdivision of a suborder or super-family. It contains similar genera. The names of botanical families usually end in aceae.

Gelatinous fiber. A fiber, the inner wall of which appears in the light microscope to be more or less gelatinous or jellylike.

Inner bark. Tissues in the cylindrical axis of a tree immediately outside the cambium; includes the region of the secondary phloem from the cambium to the last-formed periderm.

Lumen. The space enclosed by a cell wall, especially after the contents have disappeared.

Outer bark. Tissues in the cylindrical axis of a tree immediately outside the inner bark; includes the tissues from the last-formed periderm to the outer surface of the bark; the rhytidome.

Paratracheal. Said of xylem parenchyma in hardwoods which occurs in association with the vessels but nowhere else.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Pentosan. A gum made up of pentose sugars, e.g., arabinose and xylose, by condensation.

Periderm. Term applied to the cork cambium (phellogen) and the tissues (phellem and phelloderm) derived from the cork cambium.

Phellem. Cork. Suberized cells formed in the outside regions of a stem or root, from a phellogen.

Phenols. Compounds having a hydroxyl group substituted for a hydrogen atom in a benzene ring.

Phloem. The vascular tissue which conducts synthesized foods in vascular plants. It is characterized by the presence of sieve tubes, and in some plants companion cells, fibers, and parenchyma.

Phloem fiber. An element of sclerenchyma (or a strand of such elements) in the phloem. It probably helps to support the sieve tubes.

Phloem parenchyma. The unspecialized cells found in the phloem.

Phloem ray. The part of a vascular ray that passes through the phloem.

Race. A subspecies, which forms a genetically, and usually geographically, distinct mating group within a species.

Ray. Ribbon-shaped strand of tissue extending in a radial direction across the grain.

Resin. An acidic substance, either a phenolic derivative or an oxidation product of terpenes. The resins are insoluble in water but soluble in alcohol, ether, and carbon disulphide, and burn with a sooty flame. They are products of secretion or disintegration which are usually found in special cavities or passages.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin or turpentine.

Rhytidome. A tissue cut off outside a periderm. The cells die, leaving a crust made up of alternate layers of cork and dead phloem or cortex; the zone from the innermost periderm outward; the outer bark.

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*Some of these definitions were taken from Usher, G. A Dictionary of Botany. New York: D. Van Nostrand Company, Inc., 1966, 404 p.

Scalariform. Like a ladder.

Sclereid. See sclerenchyma.

Sclerenchyma. Mechanical tissue consisting of cells with thick, lignified walls and small lumens. If the cells are elongated, they are called fibers and usually occur in bundles. When the cells are oval or rounded, they are called sclereids. They occur singly or in groups.

Sclerotic. Hard, thick-walled, and often lignified.

Secondary phloem. Inner bark.

Sieve cell. A characteristic cell of softwood phloem. It translocates food materials synthesized in the plant. Sieve cells are elongated, tapering, and lack sieve plates.

Sieve tube element. A characteristic cell of hardwood phloem. It translocates food synthesized in the plant. The cells are living, thin-walled, and in longitudinal rows. They are connected by perforations (sieve plates) in their transverse walls, through which pass strands of cytoplasm.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface of a tangential section.

Tracheid. Fibrous, lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm), are as long as the vessel segments with which they are associated, and possess small bordered pits.

Tylosis. A balloonlike enlargement of the membrane of a pit in the wall of a vessel or tracheid, and a xylem parenchyma cell lying next to it. It protrudes and blocks the cavity of the wood element.

Uniseriate. Arranged in a single row, series, or layer. Also said of a vascular ray which is one cell wide in cross section.

Vasicentric. Paratracheal; forming a sheath (around vessels).

Vessel. Composite, and hence articulated, tubelike structure found in porous wood, arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the cross walls.

Xylary initials. The newly formed vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support.

Xylem. Woods. The vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support. It consists of vessels, and/or tracheids, fibers, and some parenchyma.

SUMMARY TABLE I
TRACHEID DIMENSIONS AND DECAY RESISTANCE

Species	Decay Resistance	Length, mm	Width, µm	Weight Factor (Unbleached kraft)	Coarseness mg/100 m
Eastern white pine	Intermediate	3.0	25-35	–	19.8
Red pine	Low	3.4	30-40	0.90	21.4
Jack pine	Intermediate	3.5	28-40	0.90	18.0
Loblolly pine	Intermediate	3.6	–	1.45	23.5
Slash pine	Intermediate	4.6	–	–	–
Longleaf pine	Intermediate	4.9	35-45	–	–
Shortleaf pine	Intermediate	4.6	–	–	–
Virginia pine	–	2.1	–	1.00	17.0
Sand pine	Intermediate	3.9	–	–	–
Pond pine	Intermediate	3.0	–	–	–
Pitch pine	–	3.6	–	–	–
Ponderosa pine	Low +	3.6	35-45	–	26.0
Jeffrey pine	–	–	–	–	–
Lodgepole pine	Low +	3.1	35-45	0.80	23.0
Western white pine	Intermediate	2.9	35-45	–	24.0
Sugar pine	Intermediate	5.9	40-50	–	–
Eastern larch	Intermediate	3.6	25-35	1.00	–
Western larch	Intermediate	5.0	40-50	1.20	32.5
White spruce	–	3.3	25-30	0.90	–
Red spruce	Low +	3.3	25-30	0.90	–
Black spruce	Low +	3.5	25-30	0.90	–
Engelmann spruce	Slight or None	3.0	25-30	0.90	–
Sitka Spruce	Low +	5.6	35-45	–	–
Blue spruce	–	2.8	–	0.90	–
Douglas-fir	Intermediate	3.9	35-45	1.40-Coastal 0.90-Rockies	26-31
Eastern hemlock	Low +	3.0	28-40	0.90	–
Western hemlock	Low +	4.2	30-40	1.00	29.0
Mountain hemlock	Low +	2.0	25-45	–	–
Balsam fir	Low	3.5	30-40	0.85	–
White fir	Low	3.4	35-45	0.95	24.0
Pacific silver fir	Low	3.4	35-45	0.95	–
California red fir	Low	–	–	–	–
Noble fir	Low	–	–	1.24	–
Subalpine fir	Low	3.0	29	–	–
Grand fir	Low	–	–	0.90	–
Redwood	Very durable	7.0	50-65	–	26.8
Baldcypress	–	6.2	45-60	–	–
Northern white-cedar	Durable	2.2	20-30	0.60	–
Atlantic white-cedar	Very durable	2.1	–	–	–
Eastern redcedar	Very durable	2.8	–	–	–
Western redcedar	Durable	3.5	30-40	0.70	15.4
Incense-cedar	Durable	3.6	35-40	–	–
Scotch pine	–	1.8-4.4	38	–	–
Norway spruce	–	3.5	27	–	–
European larch	–	3.6	46	–	–
Japanese larch	–	3.6	–	–	–

SUMMARY TABLE II
WOOD AND BARK SPECIFIC GRAVITY

Species	Wood		Bark	
	Green Volume	O.D. Volume	Green Volume	O.D. Volume
Eastern white pine	0.34	0.37	0.47	0.56
Red pine	0.39	0.51	0.27	0.32
Jack pine	0.39	0.46	0.41	—
Loblolly pine	0.47	0.54	0.33	0.56
Slash pine	0.56	0.66	0.35	—
Longleaf pine	0.54	0.62	0.45	0.53
Shortleaf pine	0.46	0.54	0.35	0.49
Virginia pine	0.45	—	0.54	0.63
Sand pine	0.45	0.51	—	—
Pond pine	0.50	0.58	—	—
Pitch pine	0.45	0.52	—	0.39
Ponderosa pine	0.39	0.42	0.35	—
Jeffrey pine	0.37	0.41	—	—
Lodgepole pine	0.38	0.43	0.38	—
Western white pine	0.36	0.42	—	0.62
Sugar pine	0.35	0.38	—	—
Eastern larch	0.49	0.56	—	0.63
Western larch	0.48	0.54	0.33	—
White spruce	0.37	0.42	0.39	0.65
Red spruce	0.38	0.43	—	0.60
Black spruce	0.40	0.45	0.42	0.60
Engelmann spruce	0.31	0.35	0.51	0.80
Sitka spruce	0.37	0.42	—	0.63
Blue spruce	—	—	—	—
Douglas-fir	0.45-Coastal 0.40-Rockies	0.51-Coastal 0.45-Rockies	0.41-Coastal	—
Eastern hemlock	0.38	0.43	0.43	0.51
Western hemlock	0.38	0.44	0.45	0.59
Mountain hemlock	0.43	0.49	—	0.46
Balsam fir	0.34	0.37	0.40	0.63
White fir	0.35	0.39	—	0.62
Pacific silver fir	0.35	0.42	—	0.68
California red fir	0.37	0.42	—	0.50
Noble fir	0.35	0.40	—	0.56
Subalpine fir	0.31	0.34	—	0.52
Grand fir	0.37	0.41	—	0.61
Redwood	0.38-Old Growth 0.33-2nd Growth	0.41-Old Growth	—	0.46
Baldcypress	0.42	0.47	—	0.55
Northern white-cedar	0.29	0.31	—	0.46
Atlantic white-cedar	—	—	—	—
Eastern redcedar	—	—	—	—
Western redcedar	0.31	0.34	0.36-Inner 0.38-Outer	0.44
Incense-cedar	0.35	0.38	—	0.27
Scotch pine	—	0.49	—	—
Norway spruce	0.37	0.43	—	—
European larch	0.49	0.55	—	0.35
Japanese larch	0.48	—	—	—

SUMMARY TABLE III
CALORIFIC VALUE OF WOOD AND BARK
(OVEN-DRY UNLESS OTHERWISE STATED)

Species	Wood kg cal/kg[a] Million kg cal/air-dry cord[b]	Bark kg cal/kg
Eastern white pine	3553[a](air-dry)	–
Red pine	5.0[b]	5039
Jack pine	4962[a]	5219
Loblolly pine	4780[a]	5178
Slash pine	4381[a](air-dry)	5000
Longleaf pine	4381[a](air-dry)	5162
Shortleaf pine	4381[a](air-dry)	5173
Virginia pine	–	–
Sand pine	–	–
Pond pine	–	–
Pitch pine	–	–
Ponderosa pine	5067[a]	5343
Jeffrey pine	–	–
Lodgepole pine	5.1[b]	5213
Western white pine	4.7[b]	–
Sugar pine	–	–
Eastern larch	5.8[b]	5006
Western larch	6.6[b]	–
White spruce	4.1[b]	4739
Red spruce	4.6[b]	4795
Black spruce	4.8[b]	4784
Engelmann spruce	4.4[b]	4644
Sitka spruce	4.0[b]	–
Blue spruce	–	–
Douglas-fir	4167[a]	5535
Eastern hemlock	4937[a]	4890
Western hemlock	4723[a]	5444
Mountain hemlock	–	–
Balsam fir	3.9[b]	4923
White fir	–	–
Pacific silver fir	4.2[b]	–
California red fir	–	–
Noble fir	–	–
Subalpine fir	–	–
Grand fir	4.4[b]	–
Redwood	–	–
Baldcypress	–	–
Northern white-cedar	4.1[b]	–
Atlantic white-cedar	–	–
Eastern redcedar	–	–
Western redcedar	5389[a]	–
Incense-cedar	–	–
Scotch pine	–	–
Norway spruce	–	–
European larch	–	–
Japanese larch	–	–

SUMMARY TABLE IV
CHEMICAL COMPOSITION OF WOOD

Species	Lignin, %	Alpha-Cellulose, %	Hemi-Cellulose, %	Total Pentosans, %	Solubility in Alcohol-Benzene, %	Solubility in Hot Water, %
Eastern white pine	26.6	46.0	14.3	14.8	6.5	4.8
Red pine	24.8	47.3	15.1	9.0	3.5	4.8
Jack pine	28.3	45.2	16.2[a]	11.3	4.0	3.0
Loblolly pine	28.6	44.5	15.3	12.5	3.2	2.4
Slash pine	26.8	47.3	–	10.0	3.4	2.3
Longleaf pine	28.5	47.7	–	11.8	4.7	3.6
Shortleaf pine	26.4	47.2	–	12.1	3.6	2.1
Virginia pine	–	–	–	–	4.1	–
Sand pine	27.2	42.9	–	6.9	2.2	2.5
Pond pine	42.3	25.7	–	11.3	2.2	0.5
Pitch pine	–	58.7	–	–	–	–
Ponderosa pine	25.6	37.4	–	9.4	4.4	5.0
Jeffrey pine	–	–	–	–	–	–
Lodgepole pine	27.2	45.7	–	12.4	3.5	2.7
Western white pine	25.9	40.4	–	8.4	8.3	4.1
Sugar pine	26.8[b]	–	–	10.4[b]	3.8[b]	3.1[b]
Eastern larch	26.2	44.4	–	8.3	2.0	4.6
Western larch	26.8	50.0	–	10.2	1.4	8.8
White spruce	29.4	42.6	–	11.8	2.0	2.6
Red spruce	30.0	44.7	–	11.5	1.9	2.5-Sapwood 3.4-Heartwood
Black spruce	27.6	48.6	17.4	10.0	2.2	2.1
Engelmann spruce	26.3	44.3	–	9.2	2.8	3.7
Sitka spruce	27.9	44.8	–	8.6	2.4	3.9
Blue spruce	–	–	–	–	–	–
Douglas-fir	27.7	49.6	14.1	7.9	4.1	5.0
Eastern hemlock	33.9	41.0	12.5[a]	7.3	4.0	3.4
Western hemlock	29.4	49.2	15.5	9.2	2.6	2.0
Mountain hemlock	27.0	42.6	–	7.0	4.6	4.8
Balsam fir	29.4	49.4[c]	15.4[a]	6.4	3.2	3.6
White fir	27.4	–	–	8.9	1.4	1.6
Pacific silver fir	28.2	43.8	–	9.8	2.6	3.2
California red fir	–	–	–	–	–	–
Noble fir	29.3	42.8	–	9.0	2.7	2.3
Subalpine fir	28.8	45.6	–	8.5	2.8	2.8
Grand fir	28.4	45.9	–	9.4	3.0	1.8
Redwood	34.5	38.2	–	9.4	–	9.9
Baldcypress	35.2-Sapwood 32.7-Heartwood	–	–	8.6-Sapwood 7.3-Heartwood	–	1.9-Sapwood 3.2-Heartwood
Northern white-cedar	30.2	46.2	–	13.6	6.0	5.3
Atlantic white-cedar	–	–	–	–	–	–
Eastern redcedar	–	–	–	–	–	–
Western redcedar	30.9	44.0	14.6	9.0	14.1	11.0
Incense-cedar	37.7	46.9	–	10.6	–	5.4
Scotch pine	27.3	47.2	–	9.3	4.4	1.9
Norway spruce	27.6	–	12.1[d]	11.0[e]	1.5	0.7
European larch	30.5	38.2	–	12.1	2.5	–
Japanese larch	–	–	–	–	–	–

[a]Corrected for ash.
[b]Sapwood only.
[c]Corrected for ash and lignin.
[d]Alkali extraction of wood.
[e]Corrected for uronides.

SUMMARY TABLE V
CHEMICAL COMPOSITION OF BARK

Species	Ash, %	Volatiles, %	Fixed Carbon, %	Solubility in Alcohol-Benzene, %	Solubility in Hot Water, %
Eastern white pine	1.2	–	–	15.5	–
Red pine	1.3	–	–	5.8	–
Jack pine	1.7	74.3	23.6	15.3	3.0
Loblolly pine	0.8	–	–	8.5	7.8
Slash pine	0.7	–	–	8.4	3.7
Longleaf pine	0.6	–	–	8.8	–
Shortleaf pine	1.2	–	–	7.7	–
Virginia pine	2.2	–	–	8.2	–
Sand pine	–	–	–	–	–
Pond pine	–	–	–	–	–
Pitch pine	–	–	–	–	–
Ponderosa pine	0.7	73.4	–	15.7	–
Jeffrey pine	–	–	–	–	–
Lodgepole pine	2.1	–	–	15.7	5.6
Western white pine	–	–	–	–	–
Sugar pine	0.6	–	–	–	3.2
Eastern larch	–	–	–	–	–
Western larch	2.0	–	–	14.4	3.8
White spruce	3.8	72.5	24.0	16.0	–
Red spruce	3.3	72.9	23.7	–	–
Black spruce	2.2	74.7	22.5	14.7	9.2
Engelmann spruce	2.6	–	–	24.4	–
Sitka spruce	–	–	–	–	–
Blue spruce	–	–	–	–	–
Douglas-fir	1.4	70.6	25.9	16.4	–
Eastern hemlock	2.0	72.0	25.5	25.4	3.3
Western hemlock	1.9	74.3	–	11.7	–
Mountain hemlock	–	–	–	–	–
Balsam fir	2.8	–	–	19.5	2.7
White fir	–	–	–	–	–
Pacific silver fir	–	–	–	–	–
California red fir	–	–	–	–	–
Noble fir	–	–	–	–	–
Subalpine fir	–	–	–	–	–
Grand fir	–	74.9	–	–	–
Redwood	–	71.3	–	–	–
Baldcypress	–	–	–	–	–
Northern white-cedar	–	–	–	–	–
Atlantic white-cedar	–	–	–	–	–
Eastern redcedar	–	–	–	–	–
Western redcedar	2.0	–	–	7.4	7.7
Incense-cedar	–	–	–	–	–
Scotch pine	–	–	–	–	–
Norway spruce	–	–	–	–	–
European larch	–	–	–	–	–
Japanese larch	–	–	–	–	–

COMMON NAME INDEX

SCIENTIFIC NAME INDEX